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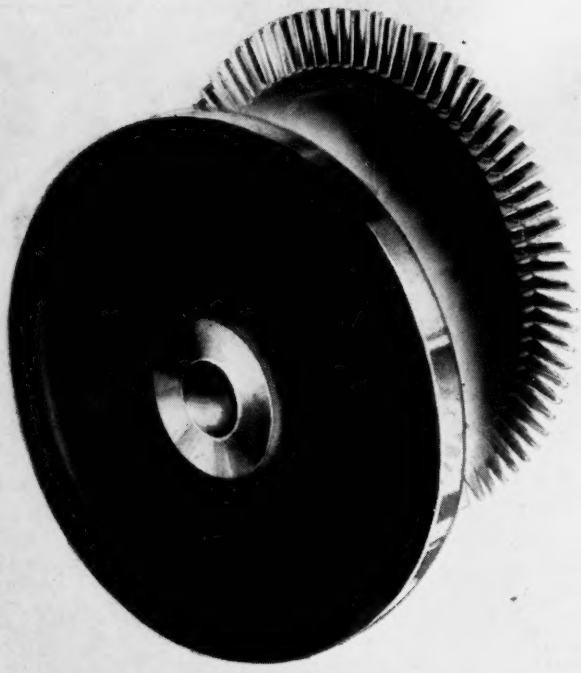
SPECIAL NOTICE

Spring Meeting, 1948—The discussion on papers presented at the first session of the meeting is given on page 376 of this issue. Owing to limitations of space the discussion during the remaining sessions must be spread over the next two or three issues of the Journal.

NOTE : The Institute as a body is not responsible for statements made, or opinions expressed, in papers, articles or discussion appearing in the Journal of The Iron and Steel Institute.



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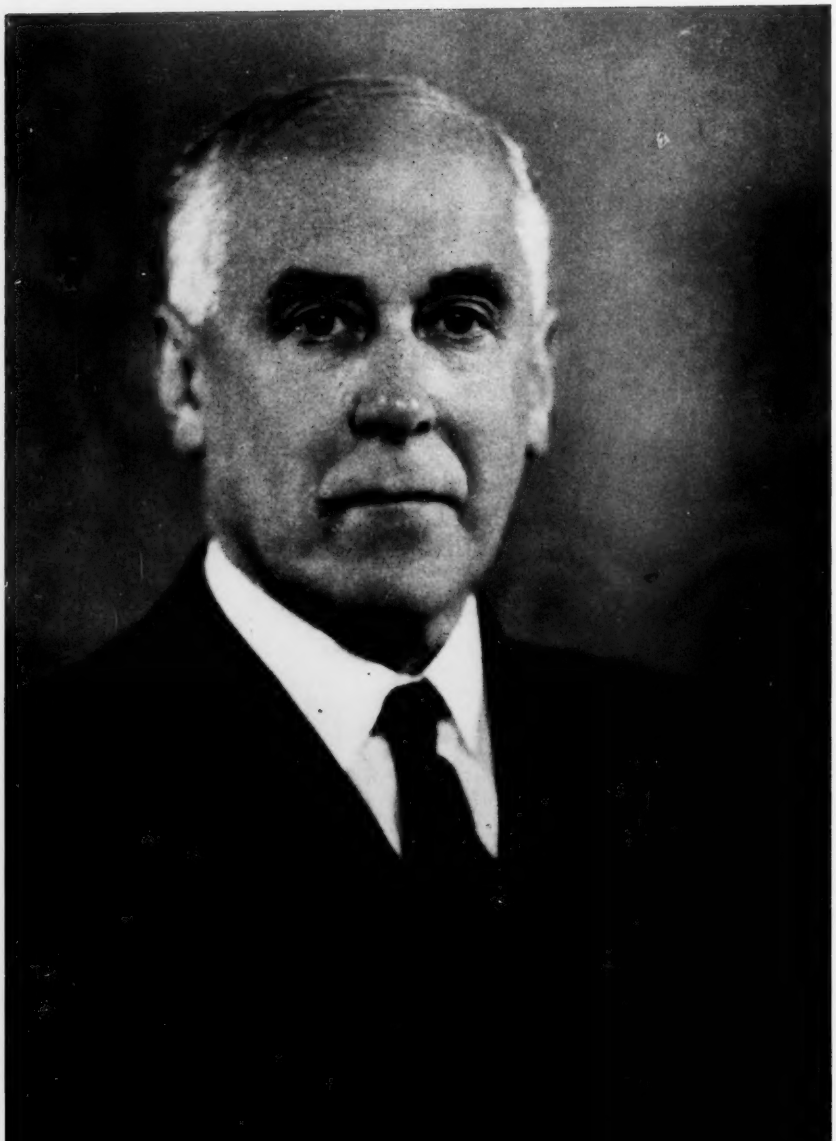
DONALD F. CAMPBELL, senior partner of Messrs. Campbell and Gifford, Ltd., consulting engineers, was educated at Winchester College and at New College, Oxford, where he took honours degrees in chemistry and mineralogy. He is an Associate of the Royal School of Mines, and was awarded the De la Beche Medal for Metallurgy in 1905.

Mr. Campbell was associated with Paul Héroult when the electric arc furnace was first used for the reduction of iron ore and the melting of steel, and he joined the technical staff of the United States Steel Corporation for a period when electric steel melting was adopted. He subsequently co-operated with P. Héroult in the construction of aluminium works in North Carolina, and in the introduction of electric steelmaking in many European countries.

In 1910 he founded the organization which is now the Electric Furnace Co., Ltd., of which he is Chairman. In collaboration with a team of engineers and metallurgists, he has introduced important new processes and equipment to the steel and non-ferrous industries in Britain and elsewhere—for example, melting and heating by induction. Other companies of which Mr. Campbell is Chairman are Davy and United Engineering Co., Ltd., and the Metallurgical Equipment Export Co., Ltd. During the recent war he was responsible to the Ministry of Supply for the construction or expansion of many metallurgical works, and eight complete steel foundries.

Mr. Campbell became a Member of The Iron and Steel Institute in 1910 and was elected to the Council in 1946. A number of papers on steel-furnace practice have been presented by him to the Institute. He is also a Member of Council of the Institute of Metals.



Donald F. Campbell, M.A., A.R.S.M., F.I.M.

Member of Council

IRON AND STEEL
INSTITUTE PAPERS

PLANT DESIGN · MANUFACTURE · RESEARCH · DEVELOPMENT

A New Theory of the Plastic Deformation in Wire-Drawing

By R. Hill, M.A., and S. J. Tupper, M.A.

SYNOPSIS

A new theory is proposed to describe the stress distribution in a wire being drawn through a die. It differs from previous work in that the stresses and the plastic region are determined by considerations of the associated deformation. The theory is based on a two-dimensional model which, however, gives results close to actual experience. The drawing load is calculated for various die half-angles between 5° and 30°, and for reductions up to 50%. It is found that earlier theories considerably underestimate the die pressure and drawing load when the reduction in area is small. In extreme cases it is shown that the die pressure increases sufficiently to cause bulging in the metal surface about to enter the die. Simple methods of allowing for die friction and work-hardening are introduced. It is shown that there is an optimum die angle giving the least load for a given reduction and given frictional conditions ; the optimum angle increases with reduction.

Introduction

MANY attempts have been made to calculate the force required to draw a wire through a die. Among early theories the most important was due to Sachs (1927).[1] Sachs' work has since been somewhat improved, principally by Körber and Eichinger (1940),[2] Davis and Dokos (1944),[3] and Lunt and MacLellan (1946).[4] Even so, the final theory is still unsatisfactory since it is based on arbitrary assumptions about the deformation and the extent of the plastic region. On the other hand, experience with other plasticity problems of axial symmetry indicates that the correct solution is likely to prove extremely difficult.

An exact solution can, however, be found for the two-dimensional analogue of wire-drawing where conditions of plane strain are prescribed. The material being drawn may be considered to be either a wide sheet, or a rectangular block in which lateral strain is artificially prevented. Apart from its intrinsic interest the plane-strain analysis has a practical value, since it is found that the calculated drawing force is close to the measured value under actual conditions. This, as we shall see, is not entirely fortuitous. Furthermore, the analysis assists a general understanding of characteristic features of the drawing process, such as the dependence of drawing force on die angle, the relatively large expenditure of non-useful work for small reductions in area, bulging in the metal surface about to enter the die, and the existence of an optimum die angle corresponding to minimum load. It has only been possible to include these features in previous theories by artificial and semi-empirical modifications.

The theory of plastic deformation under conditions of plane strain has been summarized and discussed in a recent paper.[5] The formulæ and notation of that paper will be assumed without further explanation. The theory, in the first place, postulates an ideal material which is rigid up to a well-defined yield point and does not thereafter work-harden. Elastic strains are thus neglected ; this is certainly permissible in a first treatment of drawing. It is, however, necessary to allow for work-hardening in calculations of the drawing load, and a simple treatment of work-hardening will be introduced. The present paper deals with the fundamentals of the drawing process. Such topics as the influence of back-pull, the phenomenon of bulging, and the bearing of the theory on empirical rules used in drawing practice, will be described in later papers. The present theory is also immediately applicable to an ironing process, where the wall thickness of a cup is reduced by forcing it through a die with an internal punch ; this, too, will be the subject of a subsequent paper.

DRAWING WITHOUT FRICTION

In our plane-strain model the die is wedge shaped, with total angle 2α, and cut back sharply at exit (*see* Fig. 1). For the moment the die surface is

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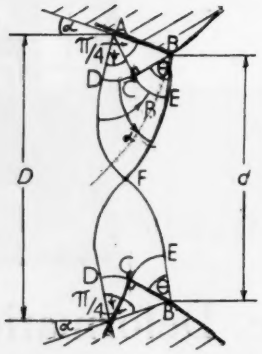


Fig. 1—Slip-line field in drawing through a smooth die

supposed to be perfectly smooth, and work-hardening is neglected. The initial and final widths of the metal are D and d, respectively.

For a certain range of the reduction in area, the slip-line field in the region of plastically deforming metal is as shown in Fig. 1.[5, 6] ABC is a region of straight slip-lines which are inclined at 45° to the die wall; in ACD and BCE the slip-lines are radii and circular arcs. DCEF is the region defined uniquely as the continuation from the circular arcs DC and CE; it has already been encountered in the problem of extrusion, where the slip-line net was calculated by a small-arc process.[5] The undetermined rigid part of the plastic region, lying outside the area of plastically deforming material, is not indicated. The magnitudes of the angles CBE = θ and CAD = ψ, are determined in terms of the dimensions of the die by the condition that the slip-lines ADF and BEF intersect the axis of symmetry at 45°. The variation of ψ with the die angle and the percentage reduction in area are shown in Fig. 2. By using the well-known geometrical property of slip-lines[5] it is easy to see that θ and ψ always satisfy the relation:

$$\theta - \psi = \alpha \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

By considering the sense in which metal crossing the curve ADF is sheared, the α and β families of slip-lines can be distinguished as indicated in the Figure.

The verification that this slip-line field is compatible with the velocity boundary conditions is straightforward. If the speed of the metal approaching the die is unity on some scale, the speed of the drawn metal is D/d, since conditions are steady and the volume change is negligible. The normal component of velocity along the slip-lines ADF and BEF is therefore known beforehand. The velocity solution can then be built up in the order DCEF, ACD and BCE, and finally ABC. Since the α lines in ADC and the β lines in BCE are straight, and since the normal velocity components are uniform along each of AD and BE, the components normal to AC and BC are also uniform.* Hence the velocity within ABC is itself uniform. But the net outflow across AB is zero, since the outflow across BEF and the inflow across ADF have been taken equal. Hence the velocity in ABC would, when calculated, be found to be parallel to AB. The proposed slip-line field is, therefore, associated with a velocity distribution satisfying all the boundary conditions. Note the remarkable circumstance that this proof has been carried through without a detailed knowledge of the slip-line field and velocity distribution within DCEF.† The latter can be calculated when required. For the moment it is only necessary to observe that there is a tangential velocity discontinuity of constant amount $(D/d - 1)/\sqrt{2}$ across the boundary separating rigid and deforming metal. This is a consequence of the assumption of a plastic–rigid material. For a real material the discontinuity would be smoothed out into a transition region which would be broader the higher the rate of work-hardening.

The stress distribution corresponding to this field is determined from Hencky's relations (equation 2 of reference 5) once the mean compressive stress is known at any one point. This is found in terms of the applied back tension from the condition for equilibrium of the undeformed metal. The required front tension is then obtained from the condition for equilibrium of the drawn metal. The slip-line field is finally justified if it can be shown that the rigid material (non-plastic, plastic, or unloaded) outside ABDEF is capable of supporting the applied stresses on it; *viz.*, the calculated distribution along ADF and BEF, and the back and front tensions. It is assumed, in the absence of the full solution, that these forces can in fact be supported by a material in which a shear stress can equal, but not exceed, K ($K = Y/\sqrt{3}$, where Y is the tensile yield stress). For an intermediate range of reductions and die angles this seems almost certainly correct on general grounds. As we shall see later, it is not true for sufficiently small reductions, where theory indicates (and experiment confirms) the formation of a standing wave or bulge in the metal about to enter the die. At the other extreme, if the calculated mean drawing stress (load/final-area)

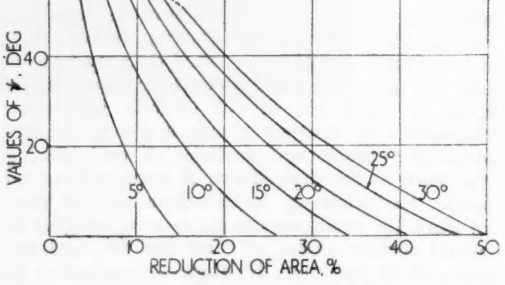


Fig. 2—Variation of angle ψ with die angle and reduction of area

* This may be immediately proved by an application of equation (2) of reference 5.

† It is assumed, of course, that the rate of work done on every element is positive, so that no element is unloaded. It is, strictly, necessary to verify this.

becomes greater than $2K$ for sufficiently large reductions, it must be presumed that drawing is impossible under these conditions.

Since the slip-lines are straight in ABC, the pressure q on the die is uniform in the range of validity of the present solution. For zero back tension, q is plotted as a function of the reduction in area $(1 - d/D)$ for various die angles as shown in Fig. 3. It will be seen that q increases greatly as the reduction is decreased, so that die wear should be more severe for light reductions than for heavy ones : q eventually reaches the value :

$$2K(1 + \pi/2 - \alpha)$$

corresponding to the dotted curve. For this value of the die pressure a part of the metal surface ahead of the die becomes incipiently plastic (*see* Fig. 4), as though the die were an indenter being pressed into the metal. For still smaller reductions the theory indicates that a bulge will form ahead of the die ; this has been observed in the ironing of cartridge cases[7] as well as in drawing solid wires.[8] The limiting value of the reduction when the bulge is just about to form will be called the bulge limit ; it is of course a function of the die angle. Bulging will be considered in greater detail in a later paper.

The drawing stress t, defined as drawing load divided by final area of drawn metal, is :

$$t = q(D/d - 1) = qr/(1 - r) \quad \text{.....(2)}$$

when the back tension is zero ; here r is the fractional reduction in area, which is $1 - d/D$ for the plane-strain model : t is shown in Fig. 5 as a function of the percentage reduction in area for a series of die half-angles (5°, 10°, 15°, 20°, 25°, and 30°). Also shown is the curve :

$$t = 2K \log(D/d)$$

the plane-strain analogue of Sachs' original theory, based on the assumption of homogeneous extension. This formula underestimates the actual drawing stress by an amount corresponding to the " non-useful " work expended in shear deformation not contributing directly to the reduction in area ; the error can be seen to be as much as 100% for low reductions. The non-useful work is proportionately greater the smaller

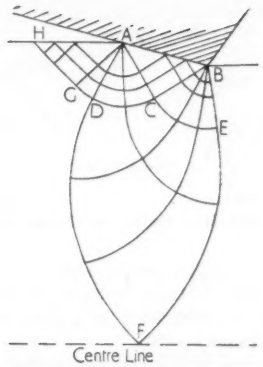


Fig. 4—Incipient bulging in metal about to enter the die

the reduction and the larger the die angle. This has seldom been evident from experimental data, owing to the masking effect of die friction. Sachs' theory also greatly underestimates the die pressure when the reduction is small.

There is an upper limit to the range of reductions for which the present solution is valid, corresponding to $\psi = 0$ and $\theta = \alpha$. We then have a special configuration in which C and D, and E and F, coincide. It is evident that the fractional reduction for which this happens is :

$$r = \frac{2 \sin \alpha}{1 + 2 \sin \alpha}. \quad \text{.....(3)}$$

This value of r represents the right-hand limit of the curves in Figs. 3 and 5. In this special case there exist simple analytical expressions for the drawing stress and die pressure :

$$\frac{t}{2K} = \frac{2(1 + \alpha) \sin \alpha}{1 + 2 \sin \alpha}; \quad \frac{q}{2K} = \frac{1 + \alpha}{1 + 2 \sin \alpha}. \quad \text{.....(4)}$$

When $\alpha \sin \alpha > \frac{1}{2}$ (*i.e.*, $\alpha > 42$–$45°$), t is greater than $2K$; the wire then fails in tension and cannot be pulled through the die. For such large angles the special solution represented by equations (3 and 4) never becomes possible, and the solution of Fig. 1

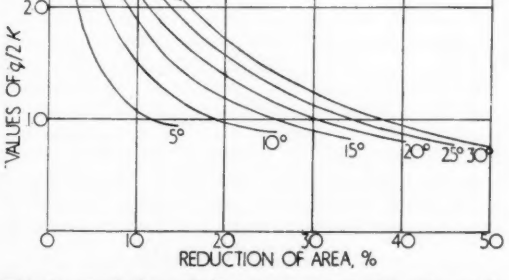


Fig. 3—Variation of die pressure q with die angle and reduction of area

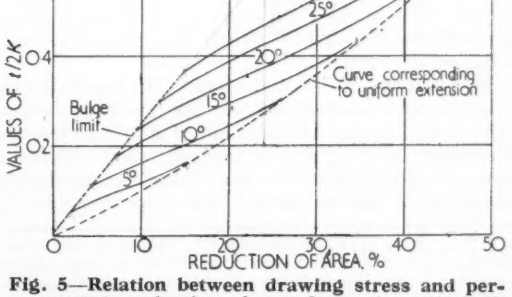
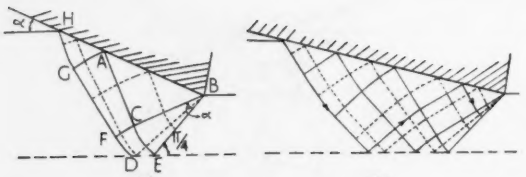


Fig. 5—Relation between drawing stress and percentage reduction of area for various die half-angles



(*a*) (*b*)

Fig. 6—Slip-line fields for large reductions

extends to the largest practicable reductions. When α is less than 42–45° there is still a range of reductions to which the solution of Fig. 1 does not extend for geometrical reasons alone.

A new slip-line field is then required (*see* Fig. 6 *a*). Region ABEC is as before. CDEF is the same type of field as in Fig. 1, but now the circular arcs defining it are CE and the reflection of CE in the axis of symmetry. ACFG is defined by the curve CF and the straight α line AC; in this region all α lines are therefore straight. AGH is defined by the β line AG and the condition that slip-lines meet the die wall at 45°. In the proof that this configuration is associated with a velocity distribution satisfying all the boundary conditions, the velocity solution must be built up beginning with region AGH (the only region where two boundary conditions are available *a priori*). It is only necessary to note that the velocity component along the curved β lines in ACFG is constant. The velocity in ABC is therefore uniform, and so the normal component across BE is constant and therefore compatible with the rigid body motion of the drawn metal. A tangential velocity discontinuity is propagated from H along the α line to D and then along the β line to B. There is no discontinuity across the exit slip-line BE. The die pressure is still uniform along AB, but rises steadily from A to H.

For still larger reductions (*see* Fig. 6 *b*) it is natural to expect that the slip-line field would be simply the continuation of the field in Fig. 6 (*a*).* It is disconcerting to find that this is not so, and the reason is curious. A velocity discontinuity is propagated from the die entrance along the arrowed slip-lines, finishing somewhere along the plastic boundary at the exit. This, however, is incompatible with the rigid-body motion of the drawn metal. So long as the discontinuity finishes on the exit corner of the die (as it will for certain ranges of D/d) the solution is valid. Otherwise the solution fails, and it is not clear what should be the correct one. A similar difficulty is met with in the compression of a block between smooth parallel plates, when the block extends outside the plates.

Fortunately, it is not necessary for practical purposes to calculate the stresses for the range represented by Fig. 6. The solution of Fig. 1 covers the reductions and die angles normally used. Furthermore, it will be seen from Fig. 5 that the asymptotic approach of the calculated curves to the curve of Sachs is already sufficiently close for an extrapolation to be made with confidence.

* This has been independently proposed by Sokolowsky,[9] who was not, however, aware of the necessity to justify the slip-line field by a consideration of velocities. Sokolowsky did not suggest any solution for the smaller reductions corresponding to Fig. 1.

COMPARISON WITH EXPERIMENT AND OTHER THEORIES

The most convenient set of experimental data appears to be that obtained by Linicus and Sachs for brass wires.[10] Linicus and Sachs estimated the friction by using rotating dies, and also obtained stress/strain curves for the drawn wires. They were thus able to make rough corrections for friction and work-hardening, finally constructing a graph of corrected drawing stress divided by yield stress plotted against the reduction in area. The agreement with Fig. 5 is remarkable, for example, in the spacing of the curves for different die angles, in the characteristic inflexion, in the asymptotic approach to Sachs' curve, and finally, in magnitude. There is a simple reason which helps to explain this possibly surprising correlation between plane-strain theory and three-dimensional experiment. If t/Y for a wire is plotted against some function of A/a (A = initial area, a = final area), and $t/2K$ is plotted against the same function of D/d for the plane-strain model, the curves must coincide for sufficiently large reductions, since the expenditure of work is very nearly the same as in uniform extension. Under these conditions $t/Y \cong \log(A/a)$ for a wire, and $t/2K \cong \log(D/d)$ for the plane-strain model. For smaller reductions it is reasonable to expect that the dependence of the drawing stress on the die angle (for the same reduction in *area*) would at least be similar in the two cases. It is difficult to judge how close the agreement really is without a valid theory for a wire. It does seem, however, that such an empirical correlation is sufficiently accurate to be useful for calculating the load in drawing practice. In short, the drawing load, for a non-hardening wire with a final area a and a yield

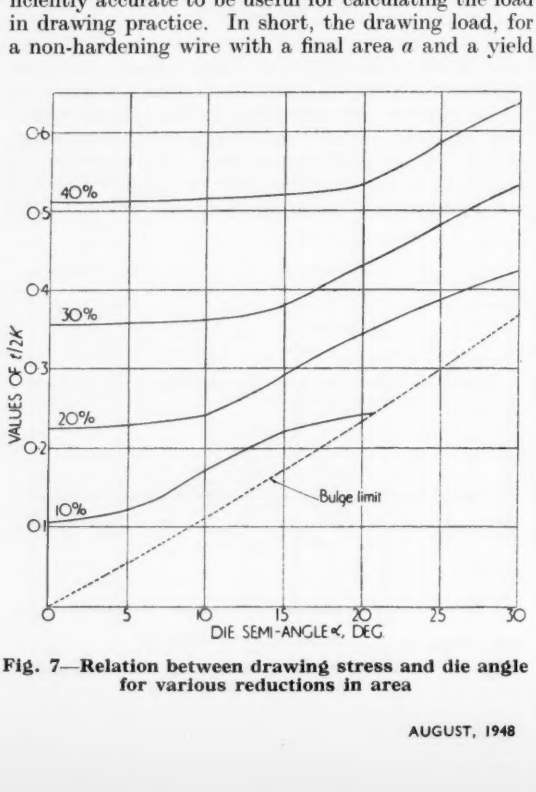


Fig. 7—Relation between drawing stress and die angle for various reductions in area

stress Y, is $Ya \times$ the ordinate of Fig. 5 for the corresponding die angle and reduction in area.

It is interesting to regard the expenditure of non-useful work in small reductions by considering the variation in drawing stress with die angle for a given reduction (*see* Fig. 7). The flat part of each curve to the left is an extrapolation of Fig. 5 towards Sachs' limiting curve. Departure from the horizontal through the intercept on the ordinate axis gives a direct measure of the non-useful work. The dotted curve marks the bulge limit. For a given reduction, an increase of die angle produces an increase in die pressure, and ultimately the bulge limit is attained for some critical angle, unless tensile failure interposes (as it will for large reductions). Various artificial corrections to Sachs' theory have been proposed to allow for the expenditure of non-useful work. Of these corrections, that by Körber and Eichinger[2] is typical. They suggested that :

$$t/Y = \log(A/a) + 0{\cdot}77\alpha,$$

where α is the die half-angle measured in radians. This implies that the curve for each angle in Fig. 5 is spaced parallel to the asymptotic curve, and that the curves for the various reductions in Fig. 7 are parallel sloping lines. It can be seen that this is far from the truth, both qualitatively and quantitatively.

CORRECTION FOR WORK-HARDENING

For practical purposes the correction for work-hardening must be as simple as possible. It would certainly not be feasible to calculate exact solutions covering a range of die angles, reductions, and stress/strain curves, even were the exact solution known in principle and the law of hardening under combined stresses experimentally determined. On the other hand, the existing corrections for work-hardening introduced into Sachs' theory (for example, by Davis and Dokos[3]) are arbitrary and cumbersome. There is, in any case, little point in modifying a theory already much in error for an ideal material.

The correction now proposed for a work-hardening material being drawn through a *smooth* die may be stated as follows. The drawing stress is given by the area under the tensile-stress/strain curve† of the undrawn material, up to the strain equal to the ordinate of Fig. 5 for the appropriate reduction and die angle. This strain may be regarded as the equivalent mean strain imparted by the particular die ; it is implied that the deformation is independent of the material and depends only on the die dimensions. This is presumably not strictly true, but it is probably a close approximation. The rule is evidently satisfactory when the material does not harden, since we have already seen that the drawing stress is $Y \times$ the appropriate ordinate of Fig. 5. The rule also leads to the correct result when the reduction is so large that the expenditure of work is effectively the same as in uniform extension. The equivalent strain is then just $\log(A/a)$. In general the correction may be made plausible by an argument based on the concept of a generalized stress/strain curve and the observation that the drawing stress is equal to the mean work of deformation per unit volume. The merit of the rule lies, however, in its simplicity and general appropriateness, and it is offered here on that account only.

† The stress/strain curve referred to is that where true stress is plotted against logarithmic strain.

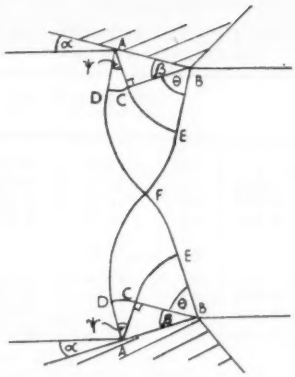


Fig. 8—Slip-line field for drawing through a rough die

If the rule be true, the yield stress of the drawn wire is equal to the ordinate of the stress/strain curve of the undrawn metal at the equivalent strain. Thus the stress/strain curve of a drawn wire should coincide with that part of the curve for the undrawn metal lying beyond the equivalent strain (apart from the effects of necking). The comparison of the stress/strain curves of drawn wires has normally been based on the assumption that the deformation in drawing is uniform extension, *i.e.*, the equivalent strain has always been equated to $\log(A/a)$. As we have seen, this is very much in error for small reductions and large die angles.

THE INFLUENCE OF DIE FRICTION

It is easy in principle to modify the slip-line field of Fig. 1 to allow for friction on the die wall. The fundamental difference is that the slip-lines in ABC do not meet the wall in 45° (*see* Fig. 8), so that the circular arcs CD and CE are no longer of equal radius. If β denotes angle ABC, and q' is the normal pressure on the die, then :

$$\cos 2\beta = \mu q'/K, \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where μ, the coefficient of friction, is supposed constant along the wall. If angles CBE and CAD are denoted by θ and ψ respectively, it follows from the geometrical property of slip-lines that :

$$\theta - \psi = \pi/4 + \alpha - \beta. \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

When there is no back tension, the drawing stress is :

$$t' = (1 + \mu \cot \alpha)(D/d - 1)q'. \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

A numerical calculation of q' inevitably depends on a trial-and-error process. For any initial choice of β the slip-line field is fixed by geometry. The normal pressure on the die, q', is then determined by the condition for equilibrium of the undeformed metal. β must be varied until this value of q' also satisfies equation (5). The numerical labour is prohibitive since the field DCEF has to be calculated afresh at each stage.

An analytical solution can, however, be found in the

Table I

TYPICAL VALUES OF DIE PRESSURE AND DRAWING STRESS.

Semi-angle α	μ	β	Reduction in Area, %	$q'/2K$	$t'/2K$
5°	0	45°	14·8	0·92	0·16
	0·039	43°	14·4	0·90	0·22
	0·079	41°	14·0	0·88	0·27
	0·121	39°	13·7	0·86	0·32
10°	0	45°	25·8	0·87	0·30
	0·041	43°	25·2	0·85	0·35
	0·083	41°	24·6	0·84	0·40
	0·126	39°	24·0	0·82	0·45
15°	0	45°	34·0	0·83	0·43
	0·042	43°	33·3	0·82	0·48
	0·086	41°	32·6	0·81	0·52
	0·130	39°	32·0	0·80	0·56
20°	0	45°	40·6	0·80	0·55
	0·044	43°	39·8	0·79	0·59
	0·088	41°	39·1	0·79	0·63
	0·133	39°	38·5	0·78	0·66
25°	0	45°	45·9	0·78	0·66
	0·045	43°	45·0	0·77	0·70
	0·090	41°	44·2	0·77	0·73
	0·135	39°	43·5	0·77	0·76
30°	0	45°	50·0	0·76	0·76
	0·046	43°	49·1	0·76	0·80
	0·091	41°	48·3	0·76	0·83
	0·137	39°	47·6	0·76	0·86

special case when $\psi = 0$ and $\theta = \pi/4 + \alpha - \beta$, corresponding to :

$$D/d = 1 + \sqrt{2} \sin \alpha \sec \beta. \quad \text{.....(8)}$$

By the use of Hencky's equations

$$t'/K = 1 + 2(\pi/4 + \alpha - \beta) + \sin 2\beta - q'/K \quad \text{...(9)}$$

when the back tension is zero. Representative values are given in Table I for typical die angles and coefficients of friction in drawing practice.

It will be observed that the drawing force is greatly increased by the presence of die friction, particularly with small die angles. On the other hand the die pressure decreases, but only slightly. This suggests the universal approximation $q' \cong q$ so that :

$$t' \cong (1 + \mu \cot \alpha)\, t, \quad \text{.....(10)}$$

where q and t are the die pressure and drawing stress for the die when smooth. This equation should also be valid to a similar approximation for a work-hardening material; in this case t represents the drawing stress for a smooth die corrected for hardening, as described in the previous section.

Equation (10) has, of course, been used frequently to estimate coefficients of friction from measurements of the drawing load, but its accuracy has hitherto been a matter of conjecture. Since the values of the coefficient of friction found in drawing practice are usually smaller than 0·1, the formula (equation 10) should be not more than 5% in error in the worst case (*i.e.*, for small die angles), and generally much less. An additional advantage of using this formula is that the sense of the error is known, the drawing stress being always slightly overestimated. Sachs and more recent workers have taken account of friction in a more complicated way, but their theories all suffer from the defect of assuming the deformation to be homogeneous extension.

For a given reduction the frictional contribution to the drawing load decreases as the die angle is increased; on the other hand the contribution from the non-useful work increases. For a given reduction and coefficient of friction there will, therefore, be an optimum die angle corresponding to minimum drawing load. We can use equation (10) and Fig. 5 to find this for the ideal material. Figures 9 and 10 show the drawing stress plotted against the die half-angle for a series of reductions, the coefficient of friction being 0·05 and 0·10, respectively. The minimum is rather flat and the optimum angle is not very well defined. In other words, from the point of view of drawing practice, the optimum conditions are fortunately not especially critical. When $\mu = 0{\cdot}05$ the variation of the optimum half-angle $\bar{\alpha}$ with fractional reduction of area r can be closely represented by the relation :

$$\bar{\alpha}^\circ = 40r\,; \; r \leq 0{\cdot}5. \quad \text{.....(11)}$$

When $\mu = 0{\cdot}10$, the optimum angle is greater, but only by about 10%. The optimum angle is somewhat

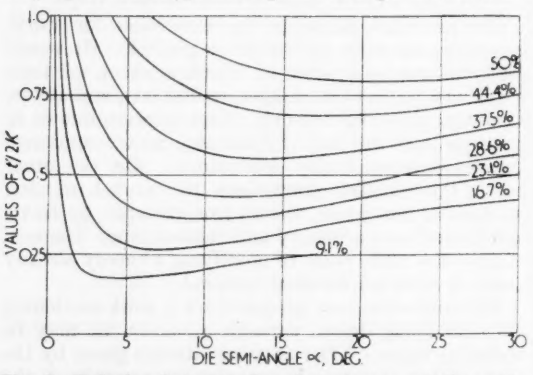


Fig. 9—Relation between drawing stress and die angle for rough die for various reductions: Coefficient of friction, 0·05

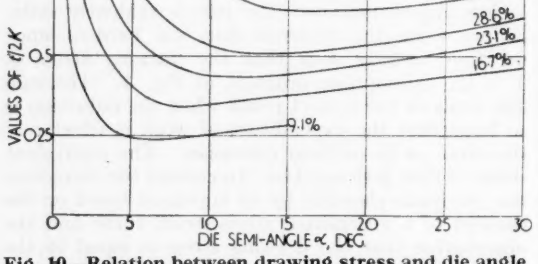


Fig. 10—Relation between drawing stress and die angle for rough die for various reductions: Coefficient of friction, 0·10

less for an annealed metal than it is for a work-hardened metal; precise values for any given stress/strain curve can easily be found, if required, by applying the correction for hardening in conjunction with equation (10) and Fig. 5. The increase of the optimum angle with increasing reduction has been experimentally observed by Linicus and Sachs,[10] and by Weiss[11] who fitted his data by the relation $\bar{\alpha}^\circ = 30r$ (coefficient of friction not known).

It may be seen from Fig. 5 and equation (11) that when drawing is done under the optimum conditions, the drawing load calculated by the present theory does not differ by more than a few per cent from that given by the homogeneous extension theory of Sachs, except at reductions of less than, say, 15%. Sachs' theory cannot, of course, predict what the optimum conditions are.

THE DEFORMATION IN DRAWING

The distortion of a square grid, supposed ruled on a longitudinal section of the wire, has been calculated for the plane-strain model with an ideal material, a smooth die, a half-angle of 15°, and a reduction of 34·1% (*see* Fig. 11). This reduction corresponds to the special configuration represented by equation (3). The calculation was based on equations (2) of the paper by Hill.[5]

In the Figure a transverse line of the grid is on the point of entering the die. The longitudinal lines in the drawn metal are still spaced equally, as a simple consequence of the steady conditions. The deformed transverse lines are also straight except over the section which passes through the curved part of the entry slip-line. The cusp on the centre line is a direct result of the tangential velocity discontinuity across the entry and exit slip-lines. It is apparently characteristic of plane-strain conditions. In the actual situation of axial symmetry the hoop strain near the axis probably prevents the formation of such a cusp, and in fact it is not generally observed. It may be shown that the total included angle 2ψ of the cusp is such that:

$$\cot\psi = 4\sin^2\alpha \qquad \text{.....(12)}$$

in the special configuration. The formula for the slope of the straight section of the transverse lines is too complicated to be worth giving here. The drawing stress for $\alpha = 15°$ and a reduction of 34·1% (*see* Fig. 5) is very close to the stress corresponding to uniform extension. The drawing process is thus in this instance a remarkably efficient means of producing the desired reduction.

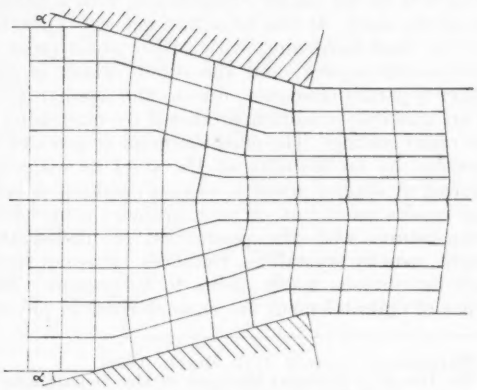


Fig. 11—Deformation of a square grid for $\alpha = 15°$ and a reduction of 34·1%

Acknowledgment

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Historical Note No. 7

A British Blacksmith in Roman York

By Dr. H. R. Schubert

After the occupation of York by the Romans in A.D. 71, the town was considerably extended and developed. The military camp erected for the Roman legion stationed at York (latinized *Eburacum*) was on the left bank of the river Ouse. The civilian town, populated by the British tribe of the Brigantians, was restricted to the so-called Mount on the right bank of the river. In this town traders and craftsmen developed great activity. A large cemetery extended to the south of the civilian quarter along the Roman road to Tadcaster, and by the end of the second century A.D. this road had begun to be lined with stone memorials to the dead, some of them elaborately sculptured. One of these memorials, now in the Yorkshire Museum, York, and a photograph of which is reproduced by courtesy of the Keeper of the museum, was erected to the memory of a smith and shows a blacksmith in front of an anvil holding a piece of iron with a pair of tongs in his left hand and hammering it with a hammer in his right hand.

Development of an Improved Basic Bessemer Steel

By H. A. Dickie, D.Sc., Ph.D., F.I.M.

SYNOPSIS

The causes of the greater susceptibility of Bessemer steel to work-hardening and strain-age embrittlement, compared with open-hearth steel, are described. Methods of removing these causes are considered. The broad principles of avoiding nitrogen absorption from the air blast are elucidated and the development of low phosphorus, low nitrogen, basic Bessemer rimming, and controlled-rimming, steels in works' production is outlined. The practical results achieved are summarized and the improvement produced in the steel quality confirmed by recorded test results.

Introduction

IT HAS long been recognized among users of mild steel, that steel made in the Bessemer converter, either acid or basic, differs in certain respects from steel of very similar composition made in the open-hearth furnace. The differences in the intrinsic properties of these two broad varieties of steel are not all weighted in favour of either. Bessemer steel has the advantage of superior machinability and welding properties ; it has a higher yield point for equivalent composition and when specially processed develops the higher elastic limit required for certain applications.

The superior weldability may be attributed to the generally lower carbon content and the purity of the steel base. No contamination occurs during manufacture by the addition of impurities such as nickel, copper, or other unwanted alloy elements, which may be introduced into open-hearth steel by the use of mixed scrap. The better machinability, the higher yield point, and the development of high elastic limit and hardness by cold-working, quenching, and ageing are evidently due to factors which are present in Bessemer steel and which are absent, or present to a lesser degree, in open-hearth steel. These factors are of value in applications where the features mentioned are advantageous, but they are liable to lead to excessive hardening with accompanying embrittlement when the manufacturing or fabricating conditions are unusually onerous, and of a character unsuited to the nature of the steel.

Embrittlement of mild steel is not confined to Bessemer steel. Had Bessemer never invented his process, embrittlement and brittle fracture would still be the subject of investigation and research.[1, 2, 3] Many of the published papers on strain-age embrittlement, blue-brittleness, quench-ageing and low temperature brittleness deal exclusively, or mainly, with open-hearth steels.[4] Brittle fracture can be induced in any steel if the right (or the wrong) methods are applied. Every steel has its limit.

The question, therefore, in the present case is not necessarily what are the ultimate causes of brittleness in mild steel, but what are the factors which cause Bessemer steel to behave differently from open-hearth steel, and how can these be modified and controlled ? Once the distinctive factors are removed, further adjustment of the inherent properties may remain desirable for particular applications, just as in the case of open-hearth steel.

This paper gives an outline of an endeavour to find a practical solution to this problem. The work has covered a period of about ten years, but was severely curtailed during the war. Experience has shown that the subject is full of many unforseen difficulties. However, the reader is asked not to assume that the author's avoidance of an unduly tedious extension of data implies that no further support exists for the views expressed. An attempt is made to bring out the highlights in the growth of this development from the initial problem, through the clarification of the primary factors involved, to the final application in works' production. Some of the findings, and perhaps the overall integration, may have novel features, but it is believed that the bulk of the structure will be found to fit easily and, it is hoped, securely, into the framework of accredited knowledge and experience in this sphere.

NATURE OF EMBRITTLEMENT

Mild steel may suffer, or have imposed on it, various forms of brittleness. It is not intended to rationalize these here. Some forms can be accounted for in chemical terms by the constitution, with associated physical repercussions. Other forms are due rather to purely physical conditions developed in the metal. Embrittlement caused by some unwanted impurity would be an example of the first kind, whereas brittleness due to an enlarged grain-size would typify the second.

The embrittlement considered here is invariably connected, in the author's experience, with a hardening of the steel. It can be of two general types, one due to work-hardening with either subsequent or spontaneous ageing, and the other, which is of a rather separate character, due to the age-hardening of an unstable condition produced by quenching or too rapid cooling. The embrittlement is revealed, in practice, by an inability of the steel to withstand internal or applied stresses, so that cracking or splitting results usually at, or near, ordinary atmospheric temperature, with the production of unelongated, bright, usually crystalline, fractures. It is not necessary for obvious notch effects to be present. Both types of embrittlement are characterized in physical

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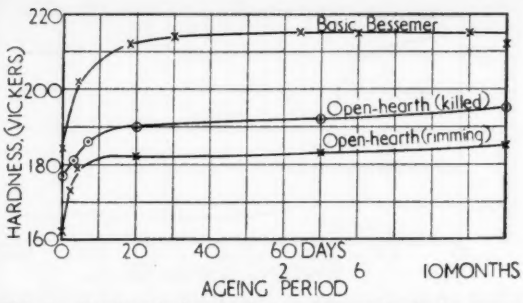

Fig. 1—Strain-age hardening at atmospheric temperature after pulling to maximum stress in tensometer machine

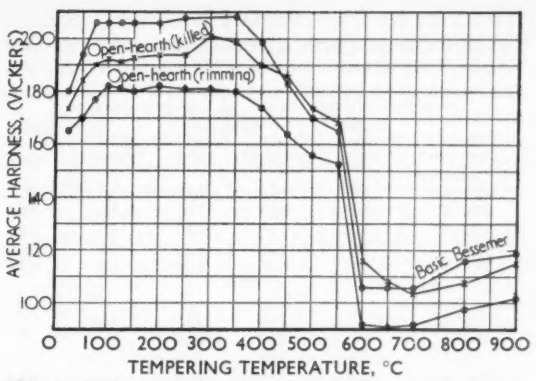

Fig. 2—Effect of reheating at various temperatures after pulling to maximum stress in the tensometer machine (1 hr. at each temperature)

tests by a pronounced lowering of the impact value from 60–80 ft. lb. Izod, in the hot-rolled or normalized condition, to a few ft. lb. in the brittle condition, and by an approximate doubling of the hardness of about 110–120 Brinell or Vickers, in the soft condition. Other properties of the steel are affected, the yield point and the tensile strength, for example, being raised. The increase in hardness (which is sometimes general, sometimes local), as stated, invariably accompanies the brittleness, and it follows, therefore, that if appropriate steps are taken to avoid excessive hardening, or to remove it, no brittleness of these types will result.

The ageing changes which occur in the work-hardening type of embrittlement, commonly called strain-age embrittlement, are illustrated in Fig. 1, which shows that after cold working, the steels increase in hardness over a period of about 10 or 14 days at ordinary temperature, to a maximum value which is maintained for a further indefinite period; partial recovery may occur when the amount of cold work is small. Raising the temperature after cold working accelerates the age-hardening, and if the temperature is raised to 100° C. or higher, the age-hardening effect is rapid, even instantaneous. Working the steel at a temperature of about 300° C., to be further referred to as "blue heat," results in still greater hardening connected with the increased stiffness of the steel at this temperature, combined with spontaneous ageing. The maximum embrittling effect produced at such a temperature falls off gradually, over a range of about ± 150° C., at higher or lower temperatures from the central point of about 300° C.

Strain-age embrittlement can be combated, without limiting the workmanship, by reheating to 600°–650° C. or, if desired, by normalizing or annealing, and it is in certain cases sufficient, or even desirable, to reheat to a lower temperature, such as 500°–550° C. following cold working, to remove some of the excessive hardening and still leave the steel in a hard condition. Heating to a galvanizing temperature (about 450° C.) may, in some cases, be sufficient to avoid subsequent cracking by ageing. The changes that occur on heating after severe cold working are illustrated in Fig. 2, which shows the additional hardening that occurs in the first 100° C., the pronounced softening at about 550° C. and above, and also the differences between ordinary Bessemer steel and open-hearth mild steels.

A practical example of this type of embrittlement is illustrated by the hardening of tubes reeled at a black heat on a mandrel bar, after tube-making in the push-bench process. Typical results, in Fig. 3, show that up to a certain maximum hardness, which in this case is 200 (Vickers), the ductility and toughness of the steel, as judged by flattening tests carried out on rings cut from the tubes, are unaffected, but that when the maximum hardness exceeds this value one encounters split tubes, or rings which split easily in the flattening test. The splits, in this case, start at the inside of the tube, which is the core of the steel in a seamless tube made of rimming steel (*see* Fig. 21) and run normal to the surface in a transcrystalline manner (*see* Fig. 22). The limiting hardness for failure by embrittlement is not necessarily 200 (Vickers) in all cases; it is seldom a lower figure, but may be a higher figure, sometimes considerably higher, depending on the particular circumstances of the case. The Izod impact value of brittle tubes is variable and may be, in parts, as low as 2 ft.lb., whereas for non-brittle tubes it is of the order of 80 ft.lb.

Embrittlement of the other type, quench-age

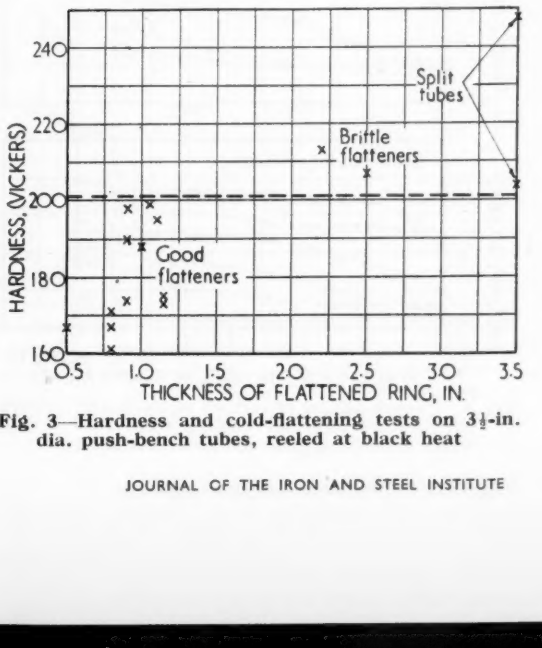

Fig. 3—Hardness and cold-flattening tests on 3½-in. dia. push-bench tubes, reeled at black heat

Table I

EFFECT OF QUENCH AGEING ON IZOD IMPACT VALUES OF BASIC BESSEMER RIMMING STEEL

Specimens heated to 1050° C., cooled in air at 300° C./min., quenched from temperatures shown. 10 × 10 mm. samples

Heat-Treatment	Ageing Period, days	Hardness (Vickers) As Quenched	Hardness (Vickers) Aged	Izod Impact, ft.lb. As Quenched	Izod Impact, ft.lb. Aged
Oil Quenched					
680° C.	12	152	203	95	26
600° C.	12	135	160	89	21
550° C.	12	125	149	88	34
500° C.	14	126	128	92	88
450° C.	12	126	128	89	92
Water Quenched					
680° C.	7	149	213	80	18
600° C.	12	148	228	...	7
550° C.	12	148	220	...	7
500° C.	12	139	165	...	33
450° C.	12	137	148	...	86

embrittlement, develops with time after quenching, in the manner illustrated in Fig. 4, the hardness increasing with time and the impact value decreasing, as shown in Table I. The maximum effect is produced when the steel is cooled from a high temperature, such as a welding or a forging temperature, and is quenched out at around 600° C. This may occur in practice by the too early use of water sprays on forged pieces. The effects produced are lessened as the temperature

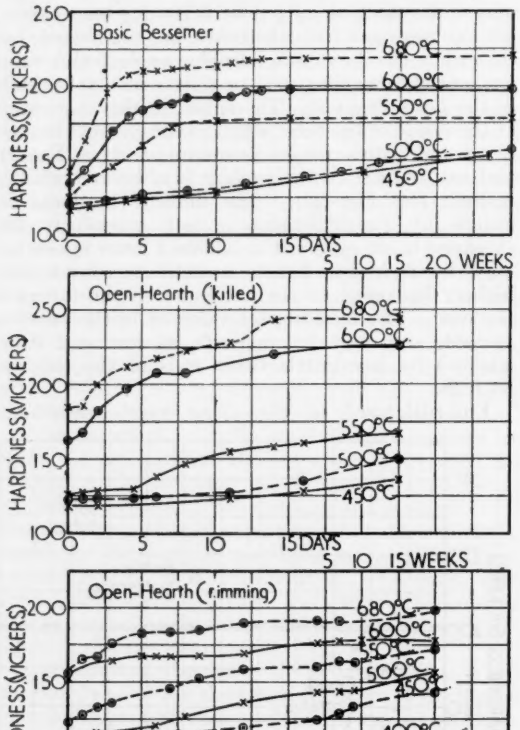

Fig. 4—Quench-ageing of various steels at atmospheric temperature after air cooling from 1050° C. and water quenching from temperatures shown

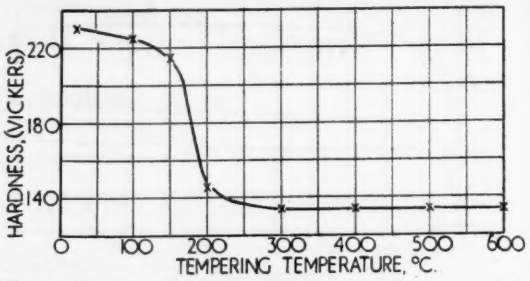

Fig. 5—Removal of quench-age hardening by tempering basic Bessemer steel (10 min. at each temperature)

of quenching is lowered ; the hardness develops more slowly over a longer period, even extending to 6 or 9 months, and the ultimate hardness figures reached are less, as Fig. 4 indicates. It is usually safe to water spray below 400° C. and it is quite safe at 300° C. or lower, provided the rate of cooling to that temperature has not been extremely rapid. Quench-age embrittlement can be removed by reheating to 300° C., either before it has had time to develop or after it has developed ; the latter case is illustrated in Fig. 5.

Open-hearth steel is susceptible to both types of embrittlement if the treatment imposed on the steel is sufficiently severe. Changes of the nature described are not absent in open-hearth steel but are less in degree.

CAUSES OF EMBRITTLEMENT

Before the ultimate causes of embrittlement can be isolated and defined it is necessary to devise, or adapt, testing methods capable of reproducing the effects, and which allow an evaluation of the factors involved to be made. Some of the standard methods of testing, such as the notched-bar impact tests, are limited and laborious in their application, sometimes on account of the size of the test-piece.

Many methods of testing have been used and suggested but few of them are capable of reproducing embrittlement in unnotched pieces. To take one example, Izod impact tests, carried out without notches, give no differentiation between brittle and tough steels, either in the strain-age embrittlement of mild steel or the temper-brittleness of alloy steel.

Provided the steel is inherently disposed to brittleness, it is possible to make unnotched specimens of a steel behave in a brittle manner if a sequence of combined thermal and deformation (or stress-imposing) operations is applied to the steel in an appropriate way. One such method, which has been used extensively as a guide in the groundwork of this investigation, is to test pieces of mild steel strip, 0·1–0·15 in. thick, by first heating to a blue heat, cupping rapidly under a hammer with a 1½-in. dia. steel ball, into a 2-in. dia. die, nearly to the point of failure (about ½ in. deep), and immediately re-flattening the cup produced. The test-piece is then allowed to go cold and is cupped in the reverse direction. This method effectively reproduces embrittlement in nearly all samples of ordinary basic Bessemer steel, the steel splitting in an ugly, splintered fashion, with a crystalline fracture, as illustrated

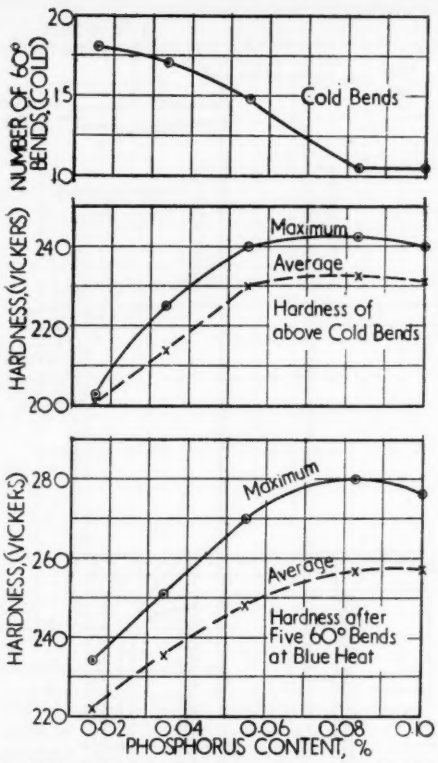

Fig. 6—Effect of phosphorus content on cold bending and hardness. Specimens 0·16 in. thick. (**Constant nitrogen content of 0·009–0·011%**)

in Fig. 23. Steels which are inherently tough behave quite differently in this test, and perform almost as well in the final cupping operation as if they had not been subjected to the preliminary treatment ; a shear fracture, of fibrous character, is produced—Fig. 24. The appearance of the cup or of the fracture can be used as a guide to the quality of the steel, as also the depth of the final cup, or the load or number of blows to produce fracture. Hardness values taken across the final fractured piece reveal a clear distinction in the hardness, that of brittle steels being of the order of 270–300 (Vickers) maximum and that of the tougher steels being of the order of 220–250 maximum.

Using this test it was found that almost all casts of ordinary Bessemer steel, acid or basic, British, American or Continental, as made about ten years ago, develop brittleness, whereas practically all qualities of open-hearth steel are free from it. The history and heat-treatment of the steel requires, however, to be known and cross-checked. The grain-size must be normal, since steel which would be tough with such a grain-size behaves in a brittle fashion when the grain-size is coarsened, although the work-hardening properties are not noticeably affected. It is possible to remove every embrittling factor such as phosphorus, nitrogen, oxygen, or carbon, from the steel, but it will behave in a brittle fashion in this test if the grain-size is too coarse.

It was early recognized, by means of this test, that occasional samples of Bessemer steel having a lower than normal phosphorus content of about 0·037% or less, give good results, and that steel properly killed in the ladle with sufficient aluminium is free from the embrittling effect, and even to some extent when it is done improperly in the mould. It was also found that low-carbon open-hearth rimming steel behaves in a brittle manner in this test when the phosphorus content is raised, for example, to 0·07%.

Another method of testing which can be effectively used is the repeated bend test carried out on strip samples $3\frac{1}{2}$ in. long × 0·4 in. wide × 0·14 in. thick, bent repeatedly through a total angle of 60°, in a bend-testing machine. The number of bends to produce failure, and the final hardness at fracture, are determined. The test can be done either cold, or at a blue heat by surrounding the apparatus with a case carrying suitable heaters, leaving the handle projecting. In this manner various combinations or sequences of operations can be carried out. The results of typical tests, shown in Fig. 6, again prove the effect of phosphorus in causing increased work hardening in basic Bessemer steel, both in the cold and at a blue heat ; in this case remelted in the induction furnace to give a constant nitrogen content. The number of bends-to-failure decreases, and the final hardness produced increases, as the phosphorus content is raised in successive stages from 0·016% to 0·10%.

Similar effects are produced when the nitrogen content is sufficiently reduced. This usually entails approximately halving the already small quantity of 0·015–0·018% of nitrogen, which only amounts to 6 or 7 nitrogen atoms to each 10,000 iron atoms ; but the reduction required is dependent on the phosphorus content. Good cupping tests are then obtained in Bessemer steel ; the initial hardness of the steel is lower, the number of bends-to-failure in the repeated bend test is increased and the final hardness is reduced, these changes occurring in either cold or blue-heat bending. These alterations occur, often to an even greater degree, when the steel is still in a fully oxidized, rimming, condition. One repeatedly-used way of proving this is to boil out the nitrogen from the molten steel.

Another method of evaluating steel quality which has been employed to an increasing extent in the later stages of this investigation is to determine the work-hardening curves of sample pieces of strip. Results, obtained on a laboratory machine, which have often been combined with ageing tests, are included later in this paper.

The effect of phosphorus on embrittlement has been known for many years.[5] The effect of nitrogen has been suspected, or asserted, many times, but has been obscured by the fact that deoxidation may improve a steel, or that a particular steel might be free from brittleness under test, and yet contain a relatively high nitrogen content. These superfieial anomalies are readily explained. What is known as deoxidation is usually an alteration in the state of combination of the oxygen, so that this element is fixed in stable oxides which do not react with carbon. Excess deoxidizer fixes the nitrogen in the different

sense of forming insoluble nitrides which do not lead to precipitation effects. Deoxidation is effective in this connection in so far as it produces nitrogen fixation.

As a result of the tests, it has been fully established, by different methods of approach, that when the phosphorus and nitrogen contents of Bessemer steel are reduced to values similar to those of the best quality open-hearth steel the differences between the steels disappear. This is not to say that these are the only factors concerned in embrittlement. It is known that open-hearth steels differ within themselves and that special treatments are necessary to produce steels for exceptional types of service, but even in these cases it is probable that the phosphorus and (active) nitrogen contents are still among the major factors involved.

METHODS OF CONTROLLING THE PHOSPHORUS AND NITROGEN CONTENTS

Dealing briefly with phosphorus, it is possible to decrease this element in the basic Bessemer converter, from the normal value of 0·050–0·055% in good practice, by using a double slagging treatment. This is carried out first by blowing in the normal manner, but with less scrap than normal, to ensure a higher temperature (to balance the chilling effect of the extra blowing); then by removing the first slag, adding further lime, and blowing for about half-a-minute. This procedure enables low phosphorus steel to be produced with 0·025% of phosphorus maximum, with the normal nitrogen content of 0·015–0·018%. Large tonnages of this type of steel have been made for cold-rolled strip at Corby in the last ten years. The method has now been superseded by the new process described later.

In dealing with nitrogen one has to consider every possibility of control, from the nitrogen present in the iron, and in all other materials used in steelmaking, as well as the effects of every type of treatment that can be applied throughout the desulphurizing processes to the steelmaking or casting, including, indeed, any possible method of removing the nitrogen from the solid steel in its final fabricated form.

NITROGEN IN THE IRON

Nitrogen exists in the blast-furnace iron in combination with elements which have a high affinity for nitrogen under reducing conditions. The elements titanium, zirconium, and vanadium are often present in small quantities in iron ore; they are wholly or partially reduced into the iron and, being more strongly basic than the other elements present, they form compounds with nitrogen. The nitrides, or carbonitrides, formed are stable in the absence of oxygen, and remain solid at iron-making temperatures, having very high melting points. They are prone to remain in a fine dispersion and are difficult to agglomerate.

It is technically possible to remove these nitrides, but it is not definitely proved that a decrease in the nitrogen content of the iron would lead to a lower nitrogen content in the final steel. If the nitrogen content of the iron is unusually high, say 0·015%, it is possible, by the modified process described later, to blow in the converter to produce steel of about half this nitrogen content. On the other hand, irons with low nitrogen contents of about 0·005% may increase during blowing to about the same value to which the high-nitrogen irons decrease. There may still remain a slight gap in favour of the low-nitrogen iron, but this could only be proved by extensive use of low-nitrogen compared with high-nitrogen iron.

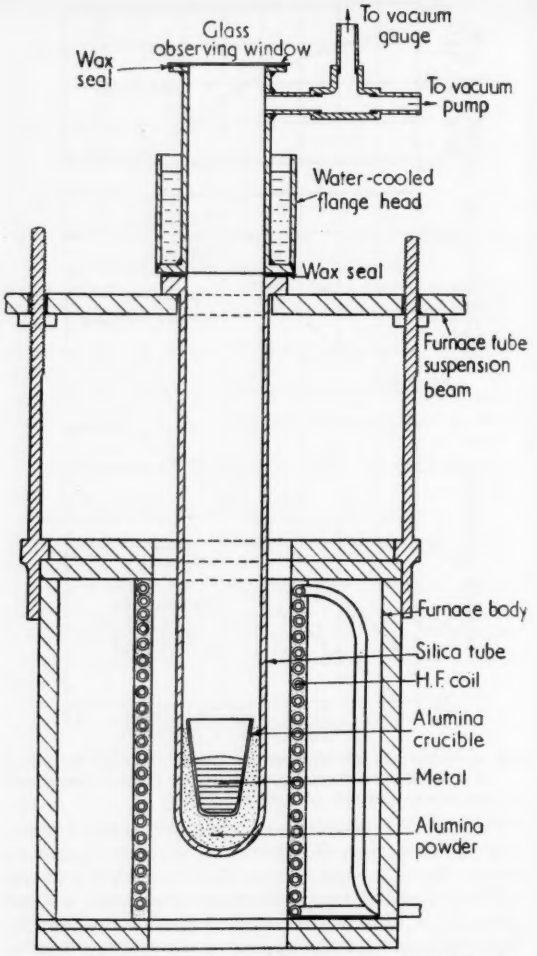

Fig. 7—Diagram of induction furnace apparatus for melting under control of atmosphere, temperature and pressure

CONTROL OF NITROGEN IN THE STEEL

There are various methods of approach to the control of nitrogen content in steel. Theoretically, there are probably half-a-dozen or more methods by the use of which a steel free from the objectionable effects of high nitrogen content could be obtained. The application of such methods to works' production on an economic basis is, however, another matter.

In general principle the nitrogen is capable of being removed from the liquid steel or from the solid steel, or it can be fixed in an innocuous condition; alternatively it can be prevented from entering the steel.

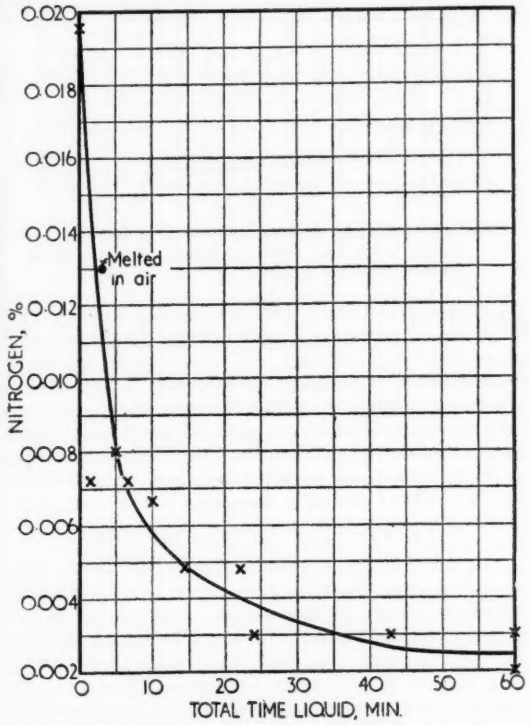

Fig. 8—Effect of vacuum treatment (0·08 mm. of mercury), on molten Bessemer steel

Removal from liquid Bessemer-blown metal has been known for many years and carried out in practice in the duplexing process, where the institution of a carbon-monoxide boil in the metal, in an open-hearth furnace, quickly removes the nitrogen to a lower level. This practice, however, is merely another way of making open-hearth steel ; it is not a way of modifying converter metal, and is not considered economic in the present case. It is not possible to treat the metal effectively, in this way, in the converter itself, without some far-reaching modification of the converter design to allow for the addition of extraneous heat, since the loss of heat is too great. It is, indeed, easy to remove some nitrogen in the converter in this way, but the initial temperature of the blown metal, before making the necessary additions, has to be higher than normal with consequently increased initial nitrogen content, which, combined with the restriction in the time factor, destroys any possibility of reaching a really low final figure.

Another way in which nitrogen can be removed is by applying a vacuum to the molten metal. Fig. 7 shows a laboratory induction furnace apparatus designed to treat small quantities of molten steel under any desired conditions of pressure or atmosphere. The application of a high vacuum to the metal in this apparatus leads to the results shown in Fig. 8, where it can be seen that a sharp decrease occurs in a few minutes, but the removal decelerates as time proceeds. Remelting alone produces a decrease in the nitrogen content, and a further decrease occurs in the vacuum in proportion to the square root of the time. The same time relationship applies in the previously mentioned case of removal by a carbon-monoxide boil. The resulting steel made by either of these methods shows the expected improvement in properties, lower initial hardness and work-hardening susceptibility, and greater toughness.

Fixation of the nitrogen can be brought about, as mentioned earlier, by adding sufficient of certain alloying elements. The most convenient of these as a rule are aluminium or titanium ; the latter involves greater weight percentages owing to its higher atomic-weight/valency ratio, and to the fact that it combines with carbon. Addition of these elements first deoxidizes the steel, the alloying element combining with the oxygen present. An excess amount of the element is required to fix the nitrogen. If insufficient deoxidizer is added, the steel will remain quiescent in the moulds for a minute or two after casting, appearing in all respects like a fully killed steel, but gasification due to release of nitrogen will then commence and extend with unfavourable consequences.

A few results of blue-heat bend tests on steels killed with aluminium are shown in Fig. 9 to illustrate the beneficial effect of this treatment on steels of normal and of low phosphorus content. The amount of aluminium recorded is the weight added to the induction-furnace casts, and is not the amount found in the final steel. The efficiency of the addition naturally affects the result in practice.

Good intrinsic properties of the steel can be achieved when the correct quantity of aluminium is added. The successive effects produced by increasing the percentage of aluminium retained in the steel are (*a*) fixation of oxygen in oxides non-reactive to carbon, (*b*) production of fine inherent (McQuaid-Ehn) grain-size, and (*c*) fixation of nitrogen ; but doubtless with overlapping. The steel when properly made is capable of withstanding the same punishment as an equivalent grade of open-hearth steel. The question of nitrogen has been resolved by virtually reducing the active nitrogen content to zero figure. Deficiencies are possible when too much aluminium is added ; the hot-deformation characteristics may be injuriously affected. The quality of the steel may be extremely poor if the additions are not uniformly diffused. It is advisable to keep the carbon content low for the best properties.

There are accompanying disadvantages to this solution of the problem. Deeply piped ingots are

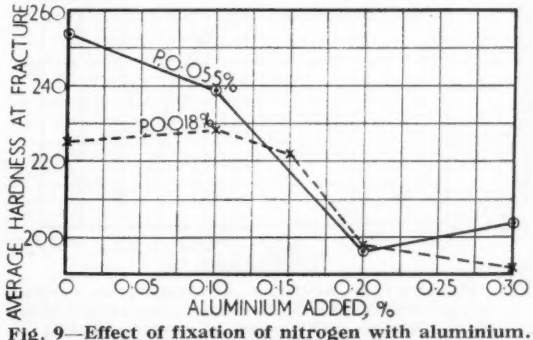

Fig. 9—Effect of fixation of nitrogen with aluminium. Final hardness at fracture of blue-heat bends

produced unless counter measures, which are difficult and expensive to apply in large-scale production, are adopted. The surface condition of the ingots and the rolled steel is injured and this is again difficult and expensive to counter. The weldability is also adversely affected, and the cost of the deoxidizer itself cannot be overlooked. In general, this approach is unsuitable where a high yield of sound steel, with the best welding properties, is essential; the steel will not meet the requirements where properties equivalent to those of open-hearth rimming steel are desired. In other cases, however desirable this grade might be to the technical requirements of a user, he would probably take a different view when confronted with the cost.

Nitrogen can be removed from the solid steel by treatment in hydrogen gas (ammonia being formed) but this is a surface reaction and is only applicable to very thin material, such as rolled strip or sheet, below perhaps 0·1 in. thick. Denitrification is very slow at high temperatures, in the γ phase, periods even of several days being required to produce a low result, and enormous grain growth takes place in the steel; this cannot be nullified except by subsequent forging. A much improved and more practicable result is achieved by treatment at lower temperatures, in the α phase; the rate of removal increases with temperature, as will be appreciated from the results in Fig. 10. It is possible then, to remove the nitrogen to a sufficiently low value in a brief period and, when the treatment is carefully adjusted, to do this without producing grain growth to an impracticable degree. The effect of time at 800° C. is illustrated in Fig. 11. There is a sharp drop even in 10–15 min., the removal being proportional to the square root of the time. Grain coarsening takes place at this temperature, and it is better to carry out the treatment at about 680° C., where little coarsening takes place. The removal is more effective when the surface of the steel is roughened, or has a coating of reduced scale. It is a feature of this method of removal, and also removal in a vacuum, or by a carbon-monoxide boil, that there is always a small residual amount of nitrogen of 0·002% left in the steel, even after lengthy treatment in a nitrogen-free atmosphere. Effective results can only be produced in the denitrification of solid steel by hydrogen, by keeping the reactive

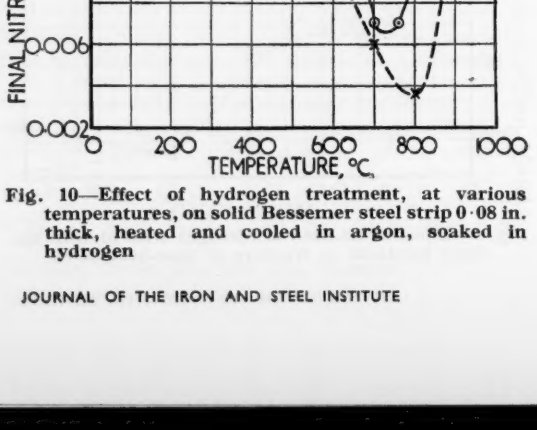

Fig. 10—Effect of hydrogen treatment, at various temperatures, on solid Bessemer steel strip 0·08 in. thick, heated and cooled in argon, soaked in hydrogen

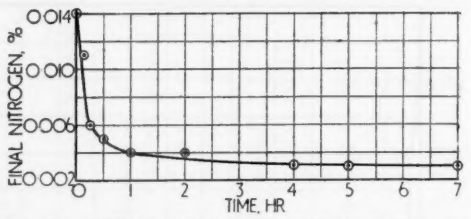

Fig. 11—Effect of time in hydrogen at 800° C., on strip 0·08 in. thick, heated, soaked, and cooled in hydrogen

atmosphere very low in nitrogen; even a small amount of nitrogen in the gas prevents the denitrification reaction from proceeding. The effect of the hydrogen treatment is to decrease the nitrogen in the surface layers to 0·002%; the action then creeps progressively into the centre, which remains at its original figure until reached by the penetration. There is always a sharp step from 0·002% nitrogen to the initial figure until the action is complete.

PREVENTION OF ABSORPTION

The method of preventing nitrogen from being absorbed from the nitrogen gas in the blast is one which makes it unnecessary to remove or fix the nitrogen picked up in the ordinary process, and which allows a rimming, or a controlled rimming, steel to be produced without further treatment. The principles on which this prevention of absorption are dependent form the main theme of the remainder of this paper, combined with a description of the procedure of carrying the principles into effect in works' production and the results achieved. In considering the possibilities it is desirable first to isolate the various factors that are operating, and to define the effect of these in as precise a form as possible before bringing them into conjunction in the most favourable way.

It is well known that the diffusion of gas into a

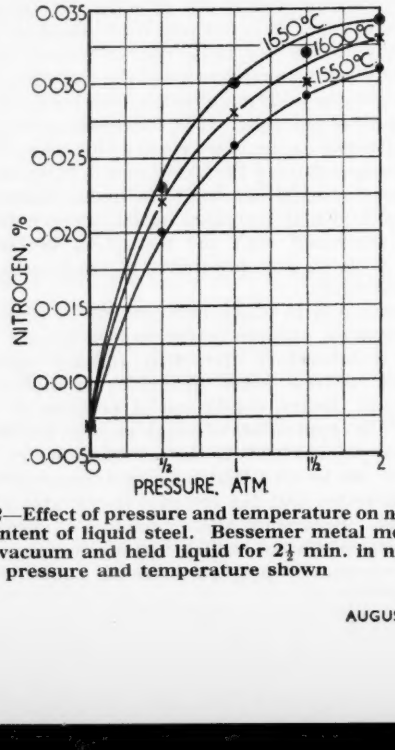

Fig. 12—Effect of pressure and temperature on nitrogen content of liquid steel. Bessemer metal melted in a vacuum and held liquid for 2½ min. in nitrogen at pressure and temperature shown

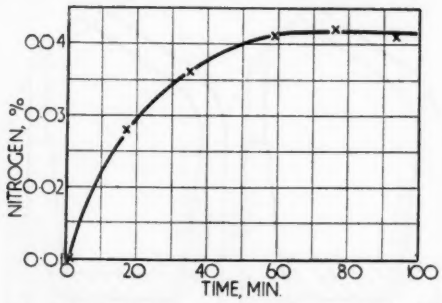

Fig. 13—Effect of time at 1550° C., on the nitrogen content of liquid steel (Eklund)

metal, or into any other substance, is dependent on the pressure, which reflects the concentration of the gas. The effect of pressure has been determined experimentally in the induction-furnace apparatus, shown in Fig. 7, with the results shown in Fig. 12 in which the pressure, varied from zero to 2 atm., is plotted against the nitrogen content of the metal after remaining liquid for 2½ min. The experiments cover three temperatures, 1550°, 1600°, and 1650° C., and therefore also reveal the effect of temperature.

It has been observed in numerous experiments that when Bessemer metal with a high nitrogen content of, say, 0·015%–0·020% is melted in the induction furnace the nitrogen content drops with almost complete regularity to 0·009%–0·011%. The mean figure (0·010%) in this range is taken as a measure of the fundamental figure in these experiments. When the increase in nitrogen content with pressure, from this basic figure (or decrease in the case of zero pressure), is plotted against the square root of the pressure, a straight line is obtained from zero pressure to beyond one atmosphere pressure. The curve departs from the straight line at higher pressures, but it is considered that this is merely because it is difficult to retain all the dissolved gas when the sample is cooled. It has not been found possible to avoid blow-holes in the samples after melting under the higher pressures.

The conclusion that the solution of nitrogen in liquid steel is dependent on the square root of the pressure is not a new one ;[6, 7, 8] the same relationship is also common in many other cases,[9] and indicates dissociation of the molecular gas into the atomic or ionic form when it dissolves in the metal.

The results of these experiments can also be used to define the effect of temperature. For this purpose the figures for the three different temperatures at one atmosphere pressure have been taken for calculation. Winkelmann[10] suggested the expression $D = aT^b$ for the diffusion of hydrogen in solid steel, where a is a constant and $b = 5$, *i.e.*, he concludes that hydrogen diffuses in solid steel in proportion to the fifth power of the absolute temperature. This expression has been adapted to the present results for the solution of nitrogen in liquid steel, and gives a straight-line relationship. The T^5 relationship, besides fitting exactly the results recorded, indicates results in converter practice which are of the correct order. On this basis an increase of temperature of 50° C. would increase the nitrogen content by about 15%, *i.e.*, by about 0·002% of nitrogen by weight in the steel, in the usual range obtained in converters. The percentage variation of nitrogen under more favourable circumstances would be the same but the alteration in nitrogen content of the steel less, that is to say, the scatter of nitrogen contents due to temperature variation would become narrower, as the mean value obtained by making other circumstances more favourable became lower. This is in accordance with experience.

The effect of time at temperature has been determined by Eklund[11] with the results shown in Fig. 13. Plotting his nitrogen figures against the square root of the time gives a straight line up to about 20 or 30 min. This square-root relationship is a very common one in metallurgy. It is a usual approximation for the solution of gases in solid or liquid metal,[9] for example, the solution of oxygen in solid silver,[12] or nitrogen in molten aluminium.[13, 14] It is also a general diffusion law which holds, for example, for the diffusion of hydrogen in iron,[15] steel,[16] and other metals,[17] and for the growth of scale on steel,[18, 19] or oxide films on many other metals.[18, 20] It indicates the exponential decelerating effect of a diminishing concentration gradient from gas to metal (or *vice versa*) as time proceeds.

The relationships between nitrogen content and pressure, temperature and time, on the bases described, are plotted in Fig. 14. The comparable results for the time factor in the vacuum treatment of liquid steel and the hydrogen treatment of solid steel are shown in Fig. 15.

Diffusion of gas into a substance is affected by the nature of the surface. In the case of molten steel an oxide film on the surface presents an appreciable barrier to the intake of nitrogen. If steel is melted under reducing or neutral conditions, and pure nitrogen gas is then allowed to contact the charge, rapid absorption results, whereas the intervention of a scum of slag or oxide produces a much slower absorption.

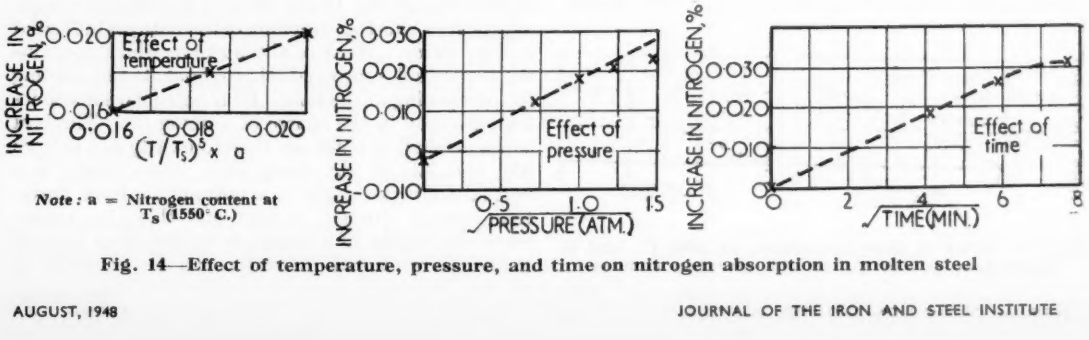

Fig. 14—Effect of temperature, pressure, and time on nitrogen absorption in molten steel

The remaining factor in diffusion, or solution, is the surface area of contact between gas and metal, to which the solubility varies in proportion.

Summarizing these five factors, the position is then as follows. The amount of nitrogen absorbed, in limited time periods, is proportional to :

(1) The square root of the partial pressure, p, of nitrogen gas in contact with the metallic charge.

(2) The square root of the time of contact, t.

(3) The fifth power of the absolute temperature, T.

(4) The surface area, A, of contact between gas and metal.

(5) The coefficient of diffusion, D, which is the percentage nitrogen absorbed at standard temperature T_s when $p = 1$, $t = 1$, $A = 1$.

Combining these factors, the percentage nitrogen absorbed :

$$Q = D(T/T_s)^5 p^{\frac{1}{2}} t^{\frac{1}{2}} A$$

The diffusion coefficient will be affected by the nature of the surface of contact between gas and metal. Under particular surface conditions the other factors of temperature, pressure, time, and surface area will modify the diffusion, as shown.

After a sufficient passage of time the internal and external pressures reach equilibrium ; no further absorption then occurs, a steady nitrogen content being maintained at constant temperature.

If the pressure is in effect reversed, *i.e.*, if the effective vapour-pressure of the dissolved ions exceeds the external partial pressure, then the nitrogen content of the metal decreases, again to a steady value at constant temperature. Increasing the temperature increases the rate of diffusion, as before. The equilibrium figure varies little with temperature between 1550° and 1700° C., judging by Eklund's figures.[11]

APPLICATION TO PRACTICE

Little or no absorption occurs in practice during the fore-blow (up to the drop of the carbon flame). The nitrogen fixed in titanium or other nitrides is first unfixed, *i.e.*, the alloy element becomes oxidized. The evolution of carbon monoxide opposes the absorption of nitrogen from the blast. It is in the later part of the blow, and particularly in the after-blow when the temperature is increasing rapidly, that nitrogen absorption rapidly increases in normal blowing.

The object in the new practice is to obtain, if possible, a conjunction of the various factors in such a manner that they all operate in the direction of ensuring less diffusion of nitrogen into the metal,

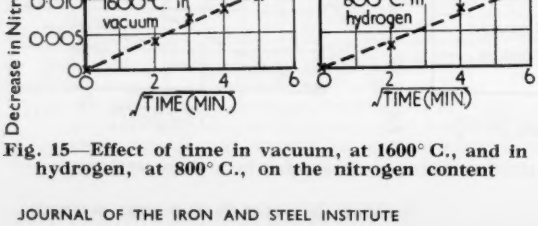

Fig. 15—Effect of time in vacuum, at 1600° C., and in hydrogen, at 800° C., on the nitrogen content

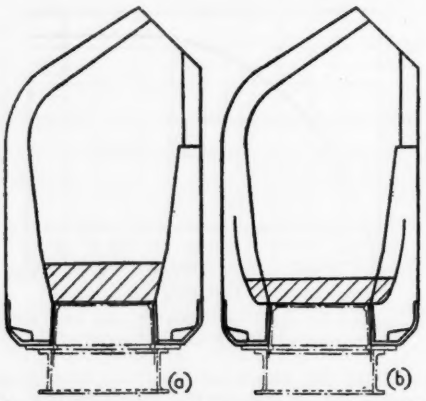

Fig. 16—Bessemer converter with conventional lining: (*a*) start of first bottom, bath, 33 in. deep, 8 ft. 2½ in. wide max. and (*b*) wear of lining up to start of fourth bottom, bath 20 in. deep, 10 ft. 6 in. wide max.

with, hence, less absorption. To make the best use of the pressure and time factors, the conditions must be balanced to secure a reduction in both. At the same time it is necessary to blow sufficient air (oxygen) through the metal to carry out the refining reactions. Decrease in the applied blast pressure alone, does not produce a lowering of the nitrogen content, since the quantity of blast per unit time of blow is decreased and the time of blow lengthened. The time that any part of the blast is in contact with the charge is also lengthened. The nitrogen content of the steel is therefore increased, not due to decrease in the pressure itself but due to the accompanying increase in the time factors. Decrease of initial blast pressure will therefore only be effective if steps are taken to maintain, or increase, the quantity of blast per unit time, per unit weight of charge, and also to minimize the time of contact.

Decreased pressure and time of contact can be brought about concurrently by decreasing the bath depth. Less head of metal then opposes the release of pressure within the charge. The blast, which commonly enters at 30 lb./sq. in. above atmospheric pressure and leaves at just above atmospheric pressure, has less pressure at any given depth, after entry, when the bath is made more shallow. At the same time, there is a shorter distance for the blast to travel through the charge. The diameter of the converter is therefore increased to make the depth more shallow, and to accommodate the full normal charge of 25–26 tons. The conventional shape of a normal converter is illustrated in Fig. 16 (*a*). Wear of the lining throughout the life leads to a widening of the bath, as indicated in Fig. 16 (*b*). Wear of the bottom, which contains the tuyere holes, proceeds throughout its life, leading to a deepening of the bath. Four bottoms, sometimes five, are used in the course of a lining life. The best times for shallow baths are therefore early in a bottom life, and late in the lining life. Blows made in a normal converter early in a bottom life have lower-than-normal nitrogen content and this also applies when the weight of a charge is smaller than normal.

The conventional converter can be modified to

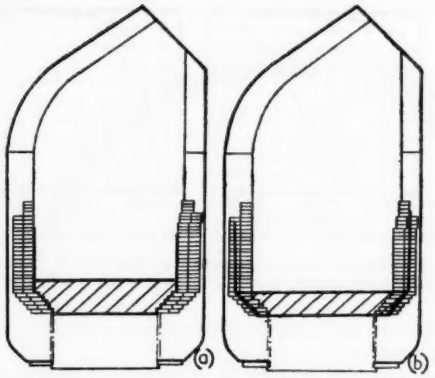

Fig. 17—New-type brick lining in shallow-bath converter: (*a*) start of first bottom, bath 24¼ in. deep, 9 ft. 6½ in. wide max. and (*b*) wear during life; start of fourth bottom, bath 16½ in. deep, 11 ft. 6 in. wide max.

secure a shallow bath without redesigning the shell. This is done by using a refractory-brick construction for the lining in its lower portion, instead of the usual tamped lining. In the present case dolomite bricks are used in place of the usual dolomitic lining mixture. The refractory bricks wear out less rapidly than the normal lining and give a comparable life. The construction of the lining is indicated in Fig. 17 (*a*), and its condition towards the end of the life in Fig. 17 (*b*). The converter nose must be kept open to avoid back pressure. When the nose becomes unduly constricted higher nitrogen figures result.

The partial pressure of the nitrogen gas in contact with the charge is further lowered by the addition of oxides to the charge, or oxygen to the blast, or by the use of both steps concurrently. When oxides, such as iron ore or mill scale, are used, direct oxidation is brought about, which protects the blast from deoxidation and keeps the nitrogen content of the gas at a lower value as it travels through the metal. The reactions are stimulated and the blow shortened. The presence of the oxide leads, paradoxically, to a slower increase of the iron oxide content of the slag ; when the bath has been blown to a normal phosphorus content of 0·05%, the slag and the steel are in a less oxidized condition than in normal blowing. The slag, which is not fully fluid, contains around 8% of ferrous oxide and the steel is in a semi-oxidized or rising condition.

In order to obtain a fluid slag for removal from the metal, and in order to obtain a metal which is easily controllable for the making of rimming or controlled-rimming steels, the blow must be continued for a brief period until the iron oxide content of the slag is increased sufficiently for fluidity (to about 12 to 14% of ferrous oxide) ; the phosphorus content of the steel is then decreased to approximately 0·03%. (The heat of reaction and the chilling effect of the blast are approximately balanced at this stage, and little or no increase occurs in the nitrogen content of the metal.) A convenient conjunction of circumstances results, therefore, in the simultaneous production of a low phosphorus and a low nitrogen content.

It is necessary, of course, to finish with a blown metal at the correct temperature. This is adjusted in normal Bessemer practice by adding the correct amount of cold scrap to the charge, in accordance with the analysis (and particularly the silicon content) of the iron. Using iron oxide additions in the new practice, it is found that a given weight of iron oxide has a greater cooling effect than scrap steel. About 50% more scrap than oxide is needed for an equivalent cooling effect. This is attributable partly to the endothermic reduction of oxide, or, what is the same thing in this case, the absence of the heat of formation of the equivalent amount of oxide which would be formed from iron and oxygen in normal blowing, and partly to the difference in the relative specific heats, the mean specific heat per unit weight of scale or ore being approximately 1·3 to 1·4 times the specific heat of scrap steel, taking the atomic heat of combined oxygen as two-thirds that of iron (which is usual). One large addition of ore or scale may be made at about the middle of the fore-blow, and a smaller addition at drop-of-flame, but this is not the only way to secure low results.

It has been explained how the pressure and time factors may be made to operate favourably by iron oxide additions. It is likely also that these additions affect the diffusion coefficient by oxidizing the surfaces of contact.

By the means outlined a sharp drop in the nitrogen content of the steel is achieved compared with normal practice. Typical results obtained throughout the life of a converter are shown in Fig. 18. The results over a series of 790 blows, using hematite ore additions, are shown in Fig. 19, compared with the results of normal practice in an ordinary converter. Many experimental blows are included in this series, which shows the significant improvement produced in the nitrogen, phosphorus, and sulphur contents.

Iron ore was later replaced by mill scale as the oxygen-bearing addition to the converter. This was equally effective in securing low phosphorus and nitrogen contents, and gave a general further improvement in the sulphur content.

A steady improvement has continued as the control of the additions relative to the iron composition has been improved, and as the operators have become more experienced in carrying out the process to the best advantage. Any process that has to provide consistent and acceptable results in large-scale bulk production has to be flexible and capable of application under varying circumstances. It is often necessary also to apply modifications within the limitations of existing plant facilities, and to make the best use of

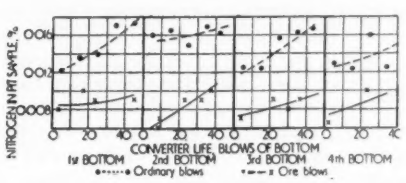

Fig. 18—Effect on nitrogen content of blowing with iron ore in a wide-bath converter

these. This was so in the present instance.

It has been found possible to produce good results with a single scale addition, averaging 3000 lb., added during the fore-blow in the place of scrap, in wide bath converters. One recent typical month's production on this basis gave the following results in the treatment of about 10,000 tons of iron :

	Average P, %	Average S, %	Average N, %	Index (P + 5N) × 1000
Within specification (301 blows) ...	0·028	0·031	0·0085	70·5
Out of specification (89 blows) ...	0·036	0·033	0·0105	88·5
Total blows (390)...	0·030	0·031	0·0090	75

Seventy-seven per cent. of the total number of blows were within the following analysis specification :

C, %	Mn, %	P, %	S, %	N, %
0·04–0·06	0·25–0·45	0·035 max.	0·040 max.	0·0100 max.

The results are plotted in the cumulative frequency curves in Fig. 20, showing at a glance the percentage of blows up to any given figure in the individual elements. It will be seen that the proportion of blows with nitrogen, phosphorus or sulphur contents below the individual limits just mentioned reach the high figures of 87%, 88%, and 95%, respectively.

Blowing can thus be carried out, even when using this simplified practice, with little or no pick-up of nitrogen compared with the content in the iron, which is commonly about 0·008–0·010%. It is by no means unusual for a decrease to occur in individual blows.

The silicon content of the iron in this period varied from 0·36% to 1·14%, with an average of 0·74%. It was at one time considered difficult to make a low-nitrogen steel with the higher-silicon irons, and this apparently placed a limitation on the effective working of the process. It has now been proved, however, that this is not so, and that a low nitrogen content can be obtained by suitably adjusting the weight of additions to the iron composition.

The undernoted results, obtained in one week's production, illustrate the best current practice at the time of writing this paper (February, 1948). Some 31% of the blows were treated with two scale additions, the remainder with one addition. The silicon content of the iron varied from 0·46% to 1·32%, with an average of 0·72%.

No. of Blows Made	No. to Specification	Blows Accepted, %	Av. P, %	Av. S, %	Av. N, %	Index (P + 5N) × 1000
100	96	96	0·026	0·030	0·0073	62·5

The complete results for nitrogen, phosphorus, and sulphur are also plotted in the cumulative frequency curves in Fig. 20, from which it will be seen that the percentages of blows with these three elements, below the individual limits mentioned above, have increased to 98%, 98%, and 99%, respectively. Only two blows out of this sequence of 100 blows exceeded the limit of 0·0100% of nitrogen, and the results are, clearly, sufficiently good to allow a tightening of the maximum limit, should this be considered advisable ; 100%

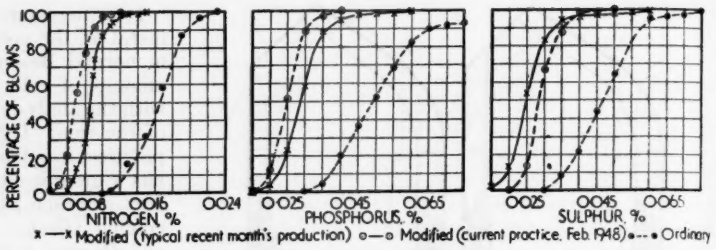
PERCENTAGE OF BLOWS
NITROGEN, %
PHOSPHORUS, %
SULPHUR, %
x —x Modified (typical recent month's production) o—o Modified (current practice, Feb. 1948) •--• Ordinary

Fig. 20—Cumulative-frequency curves for new process, using mill scale, compared with normal practice

acceptance on a whole shift or day's working is now commonplace.

As time has proceeded a larger proportion of the total production has been treated by this new process, and it seems quite within the bounds of reasonable probability that the normal Bessemer process at Corby will become obsolete and be replaced entirely by the new process. Even without this, however, in the last few years there has been an overall improvement in the quality of the normal Bessemer steel, owing to

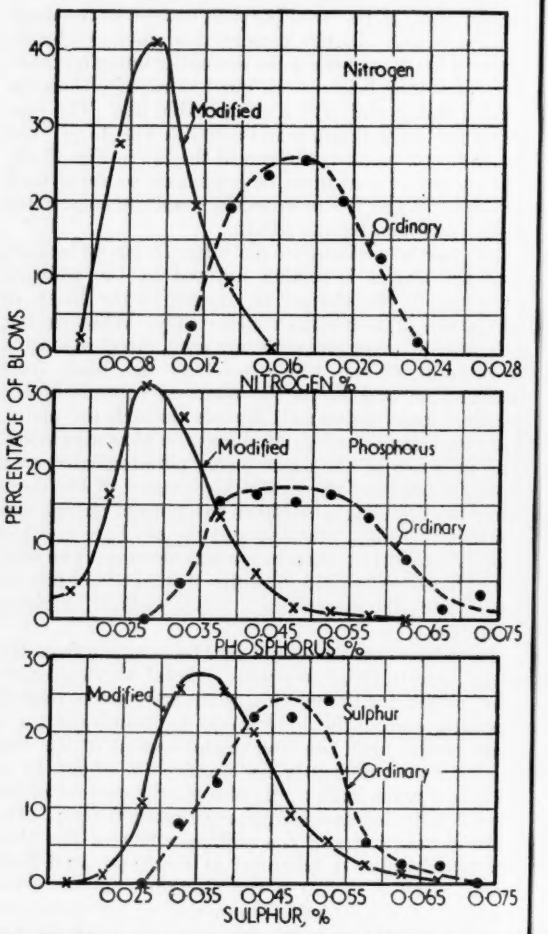

Fig. 19—Frequency curves for modified blowing, using iron ore, compared with old normal practice

Fig. 21—Sulphur print of split tube

Fig. 22—Nature of transcrystalline crack

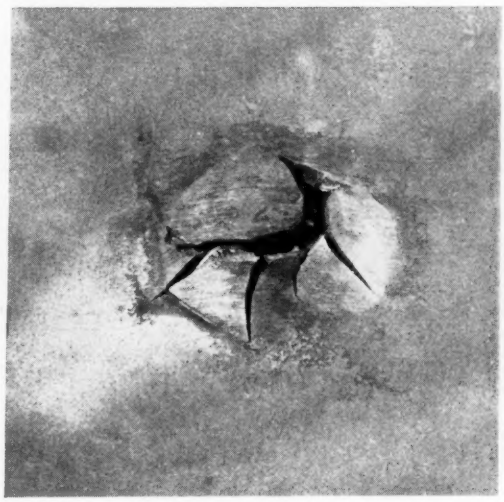

Fig. 23—Cupping test; brittle fracture

Fig. 24—Cupping test; tough fracture

[*Dickie*

[*To face p.* 370

Fig. 25—Rimming-steel ingot; sulphur print: low-phosphorus, low-nitrogen basic Bessemer steel

Fig. 26—Analyses (phosphorus and nitrogen) on rimming-steel ingot seen in Fig. 25

Fig. 27—Plugged-steel ingot; sulphur print: low phosphorus, low nitrogen basic Bessemer steel

Fig. 28—Analyses (phosphorus and nitrogen) on plugged ingot seen in Fig. 27

the fact that large amounts of modified Bessemer steel have been put to ordinary supply, and to the additional fact that the use of wide-bath converters in the ordinary process has given a general lowering of the nitrogen content.

RELATIVE IMPORTANCE OF PHOSPHORUS AND NITROGEN

The relative importance of phosphorus and nitrogen is a matter which still cannot be defined with complete exactitude. The probability is that their relative importance varies in different ranges ; for example, when one or other of these elements is extremely low. Nevertheless, after a thorough examination and balancing of accumulated data, we conclude that the basis suggested by Stromeyer,[21] in 1910, is as good a basis as any, assuming, of course, no fixation of the nitrogen. At that time Stromeyer concluded that the nitrogen content, by weight, is five times more potent than the phosphorus content. He also correctly included the arsenic content as an embrittling element less important than phosphorus ; arsenic is present in constant proportion in Bessemer metal in the present case and is therefore omitted from calculations. Results of physical tests plotted against the index $(P + 5N) \times 1000$, indicate that this is a fair working basis for assessing the relative merits of the steel in relation to work-hardening susceptibility. At the present time, the maximum index on the pit sample for plugged (controlled rimming) steel for tube-making is taken as 80, that is to say, the phosphorus content and the nitrogen content both cannot be on the maximum limits given above. A maximum of 85 is taken for rimming steel for strip, there being a larger drop in nitrogen in that case owing to greater gaseous evolution during solidification. If necessary, for unusually stringent applications, casts with a still lower index figure, say, 75 max., 70 max., or 65 max. can be selected.

If the operating factors are reduced, as in this case, to terms of chemical analysis, then a precise analytical control, with the avoidance of an intrusion of extraneously imposed factors which may vitiate the improvement sought, is considered to be the best insurance to success in practice.

TYPES OF STEEL PRODUCED

It is possible to produce the new steel in various forms: rimming, controlled rimming, or killed. The last mentioned is restricted in economic application by the lower yield of sound steel produced, and by the deterioration of surface condition and welding properties. The principal object of the process is to produce steel free from the regrettable consequences of embrittlement, without the necessity of killing the steel. The steel is maintained, therefore, in the oxidized condition and controlled to the correct oxygen content and oxygen–carbon ratio to give, at will, either a full rimming steel cast in open moulds, or a controlled rimming steel cast in plugged moulds ; these moulds have a bottle-shaped top to the mould, with a hole for insertion of the plug at the correct time to stop the rimming action.

A sulphur print taken longitudinally on a rimming ingot is shown in Fig. 25, and a similar section taken on a plugged ingot from the same cast is shown in Fig. 27. These ingots are 4 tons in weight and reveal a higher degree of quality and general uniformity than is customary in rimmed-steel production. The top portion of the ingots, in each case, is free from major segregation. The absence of columnar blow-holes in the rimming ingot will be noted.

Figures for nitrogen and phosphorus determinations made on these two ingots are shown in Figs. 26 and 28. The nitrogen content in both ingots is 0·004–0·008% throughout, even including the junction zones. The nitrogen increases very little in the top half, being still within the same limits except for the extreme head of the ingot, which is discarded, but the phosphorus content, which is 0·02–0·04% in the bottom half, increases to 0·04–0·045% in the top half. The envelope or rim, of course, is lower in phosphorus and nitrogen (and other segregating elements) than the core, due to the sweeping action of the evolved gases (which themselves contain 10–15% of nitrogen).

In practice, the lower 60% of ingots is used for the new quality of steel, advantage thus being taken of the lower phosphorus and nitrogen contents in the bottom portion, caused by inverse or negative segregation. The top portion goes to improve the general quality of normal Bessemer supply.

PHYSICAL TESTS ON THE MODIFIED STEEL

It would be of no value to lower the phosphorus and nitrogen contents if an accompanying improvement in physical properties were not produced in practice. Many tests indicate that the improvement sought is obtained, in fact, in the steel, as manufactured. The susceptibility to work-hardening is considerably reduced compared with ordinary basic Bessemer steel. This is illustrated in Fig. 29, which shows cold work-hardening curves up to 60% reduction. The modified Bessemer steel is always considerably below ordinary Bessemer steel of recognized composition, and falls in the same zone as open-hearth killed and rimming steels. Generally, the curves are above those of low-carbon open-hearth rimming steel, which is usually the softest variety of steel in this type of test, but occasionally curves falling definitely below it are obtained when the carbon and manganese contents are low. Curves for casts with index figures running down to much lower values than those illustrated, even down to an index of 40 or 30, still fall within the limits shown for the modified Bessemer steel in Fig. 29. Work-hardening curves are not only a measure of the phosphorus and nitrogen contents ; the response to cold-working depends on other elements, including manganese, carbon, and silicon. Account must be taken of these other factors in assessing the results ; for comparison, a curve for iron obtained by direct reduction of Northamptonshire ore by hydrogen, followed by further refining, is included in Fig. 29. The phosphorus content is unusually low, and this, with the low nitrogen, manganese, and carbon contents, gives a much lower curve than is obtained in the commercial steels, thereby possibly forecasting long-distance possibilities.

An improvement also occurs in the response to quench-ageing tests. Some results are shown in Fig. 30 in which the hardness of four steels over an ageing period of 7 weeks after quenching from 600° C. is shown. The element carbon enters into quench-ageing, but the hardening effect is increased by the nitrogen content, and the wide gap between ordinary Bessemer and modified Bessemer steel in Fig. 30 will be observed.

Results of tests which introduce both straining and ageing, also confirm the improvement produced in practice by lowering the phosphorus and nitrogen contents. Alternate cold-reduction in 5% steps, followed by ageing at 250° C., on a series of different types of mild steel, give the results shown in Fig. 31. The low phosphorus, low nitrogen, Bessemer steel hardens to a considerably lesser degree than the ordinary Bessemer steel, and approaches, without

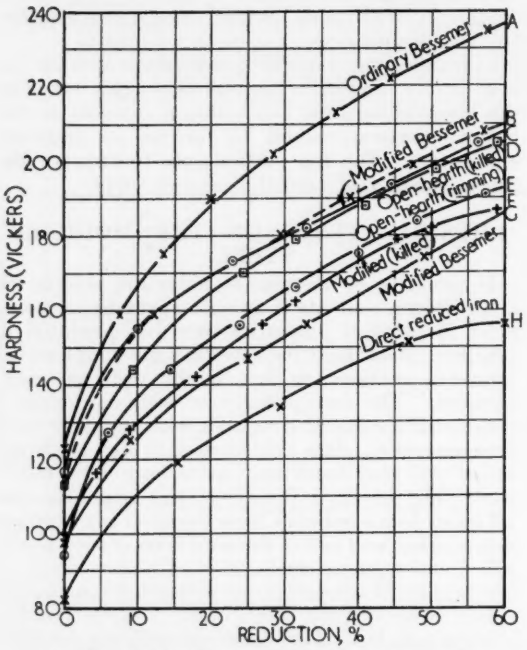

Fig. 29—Cold-rolling curves of various steels

quite reaching, the level of a silicon–aluminium killed steel. Both open-hearth steels shown in Fig. 31 are high-class basic open-hearth steels, with a very pure base, made for tube-making. The aluminium-killed steel is of the fine-grained type, McQuaid-Ehn grade 8. This is the grade of steel on which the success of the Pluto cross-channel pipe-lines, made of seamless steel pipes, depended so much in the recent war.

These particular tests cannot be carried much beyond 25% reduction, because the ordinary Bessemer steel breaks up and gives faulty hardness values. All the steels were given the same preliminary treatment. The softer character of the modified Bessemer steel is reflected also in its lower initial hardness.

The peculiar decrease in hardness in many of the tests after straining, following ageing, will be noticed

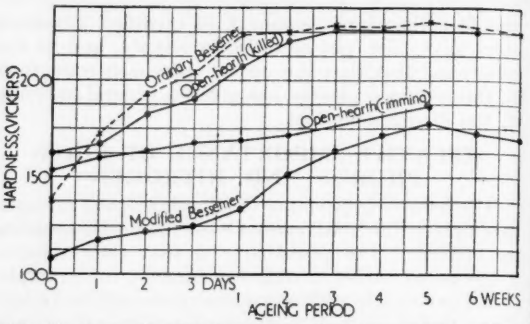

Fig. 30—Quench-ageing curves of various steels, after air cooling from 1050° C. and quenching in water from 600° C.

in the results. This is a genuine effect, apparently due to a partial destruction of the previous ageing effect. The increases of hardness on ageing tend to be rather erratic. It will be noticed that there is, on the whole, little difference in the ageing susceptibility in these widely different types of steel, as revealed by the step method of testing, which does not, however, show up this factor in the correct light.

A greater differentiation of the age-hardening effect is obtained by ageing separate samples at each stage. The increase in hardness on ageing at, say, 100° C. or 250° C. after cold-working is commonly around 30–40 points in ordinary Bessemer steel, and 15–25 points in modified Bessemer and open-hearth steels. The best types of aluminium-killed steels age 10–15 points. The increase in ageing in any particular grade of steel is fairly constant for varying amounts of cold-working, from small amounts of 5 to 10%, up to large amounts of about 80%.

The new steel also gives improved results in tests which introduce cold-working and ageing, or blue-heat working, combined with notch impact tests. It has also greater toughness under notch-impact conditions

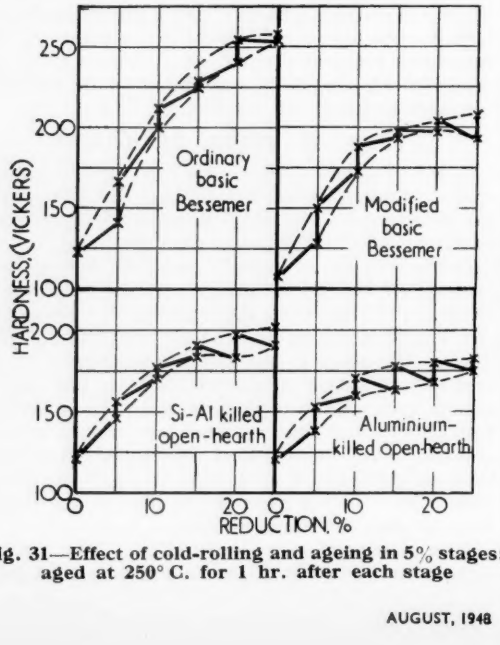

Fig. 31—Effect of cold-rolling and ageing in 5% stages; aged at 250° C. for 1 hr. after each stage

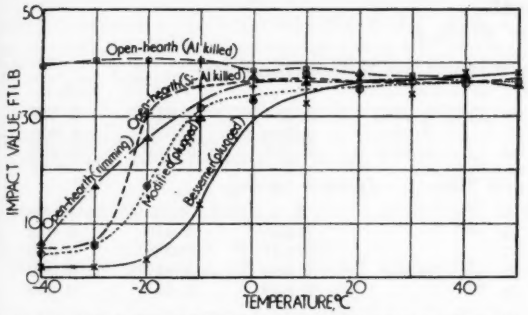

Fig. 32—Low-temperature izod impact tests on normalized 10 × 5 mm. test-piece samples

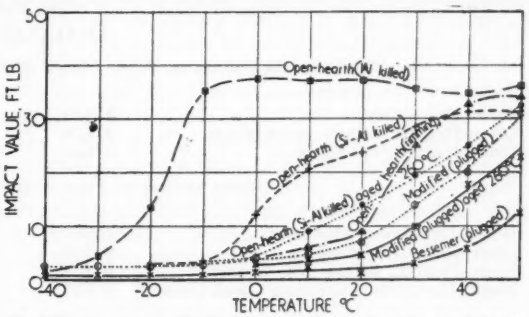

Fig. 33—Impact tests on normalized samples stretched 10% in tension, and aged at 200° C. for 1 hr. (except where marked). 10 × 5 mm. test-pieces

at temperatures below normal, either in the as-rolled or normalized condition, or in the strained and aged condition. The severity of such tests can be pushed sufficiently far to induce brittleness in the new steel and, for that matter, in almost all other steels, of whatever grade. The results are sensitive to various factors such as actual grain-size, exact nature of heating cycles, test-piece size, final testing temperature, and even the method of determining the temperature. When the ground is properly covered a clear differentiation is seen, in all cases, between ordinary Bessemer steel and the new steel, which approaches closely in its properties to open-hearth mild steels with unfixed nitrogen. Aluminium-killed steels, as is known, give still better results ; typical results are shown in Figs. 32 and 33.

A comparison of tensile properties in equivalent condition in various steels gives results of the type shown in Table II. The yield point and tensile strength of the new steel are lower compared with ordinary basic Bessemer steel, the difference in both cases being about one or two tons per square inch. Low-carbon open-hearth rimming steel is about one ton per square inch softer still. Corresponding differences exist in the hardness. The elongation is improved in the new steel and is fully equal to any open-hearth grade.

The chemical analyses of the various tests referred to in the paper are presented in Table III, which also includes the grain-sizes of izod impact test-pieces (Figs. 32 and 33).

CORROSION RESISTANCE

Corrosion tests on the improved quality steel show that it has a better resistance to corrosion than ordinary Bessemer steel, or open-hearth mild steels—killed or rimming. Tests have been carried out in boiling water for 2000 hr., and also in salt spray for

Table II

TYPICAL TENSILE PROPERTIES OF VARIOUS MILD STEELS

	Basic Bessemer Steel	Low N, Low P, Bessemer Steel			Open-Hearth Steel							Acid Bessemer		
					Rimming			Al Killed			Si Killed	U.S.A.	British	
	Continuous Weld Tube	Continuous Weld Tube	C.D. Nor. Tube	C.D. Ann. Strip	C.W. Tube	C.D. Nor. Tube	C.D. Ann. Strip	C.W. Tube	C.D. Nor. Tube	P.B. Tube	Pilger Tube	C.W. Tube	Rimming Nor. Bar	Killed Nor. Bar
Tensile strength, tons/sq. in.	26·3	24·2	23·5	21·7	23·0	22·6	20·4	24·9	24·2	28·0	28·2	26·5	25·1	27·8
Yield point, tons/sq. in.	17·2	15·0	15·1	16·4	14·0	13·6	15·7	...	16·5	18·0	14·5	17·1	17·1	18·2
Elongation :														
on 2 in., %	50·0	61	58·0	44	...	...	44	...	49	33	42·5	...	42·0	38·0
on 8 in., %	35·2	37·5	36·5	31	32	35·5	31	32	34	21	...	31·0	...	...
Hardness (Brinell or Vickers)	127	116	113	95	110	108	90	118	115	140	140	130	120	130
Analysis :														
Phosphorus, %	0·055	0·031	0·034	0·028	0·029	0·032			0·035		0·035	0·105	0·033	0·040
Sulphur, %	0·049	0·034	0·036	0·036	0·034	0·040			0·041		0·035	0·055	0·040	0·046
Manganese, %	0·43	0·45	0·395	0·28	0·40	0·42			0·48		0·48	0·42	0·37	0·48
Silicon, %	...	...	...	...	...	...			0·06		0·21	...	...	0·055
Carbon, %	0·05	0·06	0·051	0·04	0·09	0·08			0·13		0·175	0·05	0·09	0·12
Nitrogen, %	0·016	0·009	0·0096	0·0075	0·006	0·005			0·006		0·006	0·013	0·011	0·014

C.W. = continuous weld; C.D. = cold-drawn; Nor. = normalized; Ann. = annealed; P.B. = push bench

Table III

ANALYSES OF STEELS

Steels shown in Figs. 1 and 2. (Strain-Ageing and Tempering Tests)

Steel	C, %	Mn, %	Si, %	S, %	P, %	N, %
Basic Bessemer	0·040	0·46	0·009	0·037	0·053	0·017
Open-Hearth, killed (aluminium)	0·125	0·47	0·038	0·030	0·017	0·006
Open-Hearth, rimming	0·060	0·44	0·009	0·017	0·014	0·006

Steels shown in Figs. 4 and 5 and Table I. (Quench Ageing)

Steel	C, %	Mn, %	Si, %	S, %	P, %	N, %
Basic Bessemer, rimming	0·040	0·43	...	0·036	0·036	0·018
Open-Hearth, rimming	0·105	0·47	...	0·025	0·036	0·006
Open-Hearth, killed (aluminium)	0·125	0·47	0·038	0·030	0·017	0·006
Basic Bessemer rimming (Izod tests)	0·047	0·44	...	0·029	0·042	0·018

Steels shown in Fig. 29. (Work-Hardening Curves)

Steel	C, %	Mn, %	Si, %	S, %	P, %	N, %
A. Ordinary basic Bessemer	0·034	0·439	...	0·049	0·076	0·018
B. Modified Bessemer (Index 80)	0·048	0·400	...	0·023	0·041	0·0078
C. Modified Bessemer (Index 86)	0·041	0·515	...	0·021	0·032	0·0108
D. Open-Hearth (Al-killed)	0·120	0·510	0·053	0·030	0·040	0·006
E. Open-Hearth (rimming)	0·072	0·370	...	0·030	0·026	0·006
F. Modified Bessemer (Al-killed)	0·062	0·356	...	0·043	0·033	0·0093
G. Modified Bessemer (Index 71)	0·060	0·295	...	0·041	0·032	0·0078
H. Direct reduced iron (refined)	0·016	0·200	0·010	0·028	0·003	0·005

Steels shown in Fig. 30. (Quench-Ageing Tests)

Steel	C, %	Mn, %	Si, %	S, %	P, %	N, %
Ordinary Bessemer	0·050	0·410	...	0·053	0·061	0·020
Modified Bessemer	0·044	0·388	...	0·044	0·016	0·006
Open Hearth, Al-killed	0·125	0·470	0·038	0·030	0·017	0·006
Open-Hearth, rimming	0·105	0·470	...	0·025	0·036	0·005

Steels shown in Figs. 31, 32, and 33. (Strain-Ageing (Stage) Tests and Izod Impact Tests)

Steel	C, %	Mn, %	Si, %	S, %	P, %	N, %
Normal plugged Bessemer	0·054	0·438	...	0·040	0·050	0·020
Modified plugged Bessemer	0·041	0·274	...	0·030	0·025	0·0066
Open-Hearth, Si–Al-killed	0·12	0·52	0·13	0·030	0·030	0·004
Open-Hearth, Al-killed	0·12	0·51	0·053	0·030	0·040	0·005
Open-Hearth, rimming	0·060	0·350	...	0·031	0·011	0·0035

Grain-Size of Izod Impact Test-Pieces (*see* Figs. 32 and 33)

Steel	Grains/ sq. mm.	McQuaid-Ehn Grain-Size
Normal plugged Bessemer	800	Coarse
Modified plugged Bessemer	600	Coarse
Open-Hearth, Si–Al killed	400	1–4
Open-Hearth, Al-killed	1500	8
Open-Hearth, rimming	500	Coarse

Table IV

CORROSION BY PARTIAL IMMERSION IN BOILING WATER

Duration 2000 hr.; partially immersed in water at 100° C. in a covered vessel. Specimens previously pickled in sulphuric acid

Type of Material	Loss in Weight, g./sq. cm.
Open-hearth steel, Al-killed	
Cold-drawn seamless tube, annealed	0·083
	0·074
Ordinary basic Bessemer mild steel	
Hot-rolled continuous-weld tube	0·064
	0·088
Modified basic Bessemer steel	
Hot-rolled continuous-weld tube	0·039
	0·055
As cold-drawn continuous-weld tube	0·040
	0·055
Cold-drawn, annealed, flanged cold	0·049
	0·061
Cold-drawn, annealed, drifted 30% cold	0·071
	0·063
Cold-drawn, annealed, roller expanded 12½%	0·056
	0·085

300 cycles. A few typical results are shown in Tables IV and V, from which it will be seen that the modified Bessemer steel displays, in all cases, a very appreciably lower loss in weight than ordinary Bessemer steel or open-hearth steel in equivalent condition, and that even when the modified steel is heavily cold-worked, such as in expanding or flanging the ends of tubes, the rate of corrosion still remains at a figure that is as low as the other steels in the unworked condition.

An improvement in corrosion resistance was observed many years ago in the low-phosphorus double-slag steel, compared with ordinary Bessemer steel ; this improvement is increased when the nitrogen content is also lowered.

CONCLUSIONS

This paper describes the progress made up to early 1948. The position has for some time been steadily improving and is not necessarily regarded as finalized. Further improvements are being made or are contemplated ; the possibilities of making a still softer steel

Table V

CORROSION BY EXPOSURE TO SALT SPRAY

Duration: 300 cycles—15 min. spraying followed by 3 hr. standing in moisture-saturated atmosphere. Spray solution: 25 g. sodium chloride/litre. Specimens previously pickled in sulphuric acid

Type of Material	Loss in Weight, g./sq. cm.
Open-hearth mild steel, Al-killed	
Cold-drawn seamless tube, annealed	0·044
	0·047
Hot-rolled seamless tube	0·043
	0·042
Open-hearth mild steel, Si–Al killed	
Cold-drawn seamless tube, annealed	0·041
	0·044
Hot-rolled seamless tube, annealed	0·021
	0·024
Open-hearth rimming mild steel	
Cold-drawn seamless tube, annealed	0·040
	0·040
Hot-rolled seamless tube	0·039
	0·033
Ordinary basic Bessemer steel	
Hot-rolled continuous-weld tube	0·030
	0·049
Modified basic Bessemer steel	
Hot-rolled continuous-weld tube	0·017
	0·018
As cold-drawn continuous-weld tube	0·024
	0·025
Cold-drawn, annealed, flanged cold	0·025
	0·031
Cold-drawn, annealed, drifted 30% cold	0·030
	0·039
Cold-drawn, annealed, roller expanded 12½%	0·034
	0·024

are not exhausted. There may be limits, however, to the softness that is desirable. Criticisms could be quoted of mild steel which is regarded as too soft by users. It is necessary to strike a balance between softness and freedom from trouble due to hardness. Physically, the improved type of Bessemer steel, as made at present in bulk quantities, has distinctly less work-hardening and ageing susceptibility than ordinary Bessemer steel, but it is not in all respects fully reduced to the level of the softest quality open-hearth steel, except perhaps in a selected proportion of the output. This is not without its benefits ; for example, the machinability is not sufficiently affected to cause difficulties in high-speed screwing and threading operations to which the steel is applied.

Chemically, the new steel is superior to both open-hearth and ordinary Bessemer steels, because of the naturally purer base, reinforced by low nitrogen, phosphorus, and sulphur contents. The corrosion resistance is therefore enhanced and the weldability improved ; this becomes evident in furnace welding, and it also results in better surface finish, due to the self-healing of surface flaws during rolling or forging, and in increased resistance of the material to penetration or rooting of scale.

The steel is very soft magnetically, being again better than open-hearth or ordinary Bessemer mild steels, and can be applied effectively to uses requiring high permeability and low hysteresis loss, when properly heat-treated for the purpose.

A high level of consistency in both physical and chemical properties is a feature of the bulk supply. The steel has already been applied successfully, in both strip and tubular form, to a variety of uses, to which the ordinary type of Bessemer steel could not be applied.

The methods of production used at present in the steelworks are merely an adaptation of existing plant facilities. Assuming the possibility of redesigned converters, and other measures involving capital outlay, the application of the principles outlined in this paper would be likely to lead to a still closer control and a further widening of the possibilities.

Acknowledgments

The author desires to acknowledge the many vital contributions on the metallurgical, analytical, and practical sides, made in the course of this development by members of the research and production staffs at Corby. He also desires to express his thanks to the Company's Managing Directors who initiated and supported this work, for their unfailing encouragement and guidance, and for permission to publish the results.

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DISCUSSION ON PAPERS

DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

Spring Meeting, 1948

Joint Discussion on the Papers—

CONSTRUCTION AND REPAIR OF OPEN-HEARTH FURNACES* *by D. C. Muir*

THE DESIGN OF OPEN-HEARTH GAS PORTS† *by M. P. Newby*

INSTALLATION AND USE OF INSTRUMENTS ON OPEN-HEARTH MELTING FURNACES‡ *by R. C. Baker*

Mr. **D. C. Muir** (Consett Iron Co., Ltd.), in presenting his paper, said: Since the paper was written, the steel industry has accepted the continuous working week, and therefore the weekend shut-down, which was one of the main objections to the all-basic furnace, no longer exists. We have accordingly arranged to build one of the 150-ton fixed furnaces in a fully suspended construction with chemically bonded chrome-magnesite brick. It will have a single slag pocket and unrestricted uptake.

There will be various difficulties with all-basic construction, but we are sure that we shall overcome them in time, and we are still more sure that we shall not have the full benefits of high-quality fuels until the limitation imposed by the silica roof is removed from the basic furnace. We want the regenerators and so on to give a life such as is expected from the basic roof, in order to have balanced repairs, with a longer life. Oil firing tends to give a deposition of iron oxide in the checkers, and the problem of preventing the deposition or of accelerating its removal has not been satisfactorily solved. We hope that the unrestricted uptake resulting from the suspended construction of the furnace will help to reduce the carry-over to the checkers.

Mr. **M. P. Newby** and Mr. **R. C. Baker** briefly introduced their papers.

Dr. **J. H. Chesters** (The United Steel Companies, Ltd.), in opening the discussion, said: It must have been very gratifying to the three authors that Sir Andrew McCance opened his term of office as President with an address describing the development of the open-hearth furnace. The address was a masterly survey, and will, I feel, be a stimulus to everybody working in this field. The authors of the papers that followed showed that deep interest is being taken in refractories, in furnace design from a fundamental aspect, and in combustion control, which can make either a success or a failure of what has already been designed.

Mr. Muir emphasized a number of points, but the one which I should like to take up is that of the all-basic furnace. We have in this country an All-Basic Furnace Sub-Committee which has been working very actively for about a year now and has produced preliminary recommendations. These are merely intended to help those who want to get started and do not quite know where to begin. The Sub-Committee would wish to emphasize one point made by Mr. Muir, namely, that the main trouble at the moment is that there are no proper records of the all-basic furnaces that have already run their life. There have been, perhaps, a dozen such furnaces in this country. We have a lot of information on successful furnaces but when we try to compare one with another we find many gaps. One of our first tasks, therefore, has been to formulate (it is nearly complete) one more questionnaire—we prefer to call it a schedule—in which we ask all those who have built furnaces to keep certain records. If anyone here is going to put a furnace on, we hope he will collect this information.

In addition we are arranging work on the fundamental properties of refractories, notably the creep properties at high temperatures, without which our approach must be purely empirical. At least three firms in this country have already placed orders for all-basic furnaces, and by the end of the year there will probably be several more.

Mr. Muir also touched on basic insulating bricks. So far such bricks have had virtually no application, but we feel that ultimately they will have a very real application, and for the following reasons: (1) The cost of the job, which is generally five or six times that of silica, is largely determined by the enormous raw-material cost, and (2) it is not much more difficult to make a basic brick than a silica brick, but it costs a great deal more to get started. If we would cut the weight in the brick to one-half, as we could if we made it sufficiently porous, it should have an effect on the price, though the manufacturers say that the difficulties may more than offset the savings.

All-basic furnaces will normally have higher heat losses than silica furnaces. I think that has been the experience recently at South Chicago, where the point which the President made about men working round furnaces in America in the hot summer came up in a rather aggravated form. If we could work with porous

* *Journal of The Iron and Steel Institute*, 1947, vol. 157, Dec., p. 481.
† *Ibid.*, vol. 157, Dec., p. 601.
‡ *Ibid.*, vol. 157, Sept., p. 81.

bricks with conductivities lower than silica we should have a great advantage. Moreover, the weight would be less, and the rather complex steelwork needed to deal with a brick with poor creep properties—and the chrome-magnesite brick today has very poor creep properties—should be much less expensive.

Finally, bricks made with a high porosity do not show the iron oxide bursting characteristics of solid bricks; their bursting coefficients are something like one-quarter. There is, however, the other side of the picture; these bricks are very weak, they are open to slag attack, and may fail from unanticipated causes. We are, however, going to try them in our own roofs, and Mr. Muir's firm have kindly offered to supply us with samples for this purpose.

The fact remains, however, that most of us will have to go on using silica roofs for a long time, whether we like it or not, and it is very important that we should make the most of them. Someone will say "We get fifty weeks on our roof," and we shudder because we get only eight, but later we think that they ought to be ashamed of themselves for getting fifty weeks, because it means that they are not getting the maximum output from the furnace. Then we compare what we are doing with someone who is trying to get every ounce out of his furnace, and we find that he gets twelve weeks to our eight, and wonder whether there is something wrong with our practice.

Before we can compare such figures we must have a sound basis for comparison. What does Mr. Muir think is the correct basis for the comparison of roof life, assuming that the operating conditions are reasonably similar? For instance, if during its life the whole of a roof has had to be replaced, with a patch here and a patch there, does he not think that if the total life of the roof is, say, 300 heats, the effective roof life should be given as 300/2, *i.e.*, 150? Does he think that heats are the right unit for expressing roof life, or does he prefer weeks, or even tons of output?

With regard to the paper by Mr. Newby, the President will be gratified by the aerodynamic approach adopted in this work. In his address he referred to the work on heat, by Joules, reacting with the practical desires of Siemens and resulting in a big step forward. We all hope for such a step forward in the near future as we obtain more fundamental information. In our own research department we started work on water models about a year ago. Some of the results are rather exciting but we should prefer not to make any detailed statement today. An example of what we have found is shown by the photograph in Fig. A, which was taken on our Maerz furnace model in which there is a fast jet of gas (actually water) going into the furnace chamber together with water fed through the air ports. Incidentally the water speeds are adjusted to get the right Reynolds numbers. Aluminium powder has been introduced into the central water (gas) jet, and fans out as a flame does in a furnace. It also shows a marked recirculation of the gas stream.

Fig. A.—Photograph of Maerz furnace model, showing fast jet of "gas" entering the furnace chamber. Note the recirculation

We observed this from the first, but thought it might be just the air going round in circles like a dog chasing his own tail. This photograph, which was taken with special precautions, shows beyond doubt that a substantial part of the gas turns completely round and comes back to the uptake. With more simple models, *e.g.*, a square dish, it will be found that this is almost a "law of life"; where there are jets there is almost always recirculation, and the bigger the difference in velocity the more likely it is to occur.

One problem which we are going to have to face in the near future is the difference between the production rates of oil-fired and gas-fired furnaces. Many of us are very pleased with oil-fired furnaces, because they run very fast, and at the moment cost is no particular object; but cost is going to be an object very soon, and we cannot go on spending more on oil than we would spend to make the same amount of steel with gas. If we go back to gas, instead of reporting production increases of 10% we may have to report losses of 10%. The only way we can see of avoiding this is greatly to increase the speed of the gas flame. We are not talking about small increases of, say, 5 or 10%, and we are sorry that Mr. Newby has found that the frictional factors are so small, because it means that we have only 9% on the velocity to play with. If we are going to get a really high velocity for the same volume of gas, we have to have a small port and high pressure behind it.

If we do that we are faced with two problems. The first comes from people at the producer end, who say that if we want gas at a pressure of 4–6 in. water-gauge, instead of 2 in., we are going to get poor gas. That, of course, would be crippling; the gas is poor now, and we could not afford to have it any worse. That is the first point to be tackled. I believe that co-operative research is going on at the moment between the British Coal Utilisation Research Association and the British Iron and Steel Research Association to try to overcome this limitation and that the initial results are encouraging.

The second problem is this: We get quite enough leakage on a gas-fired furnace at the moment; how much more would we get with the high pressure, and how unbearable would the stage be with two or three times as much leakage as at present? That is perhaps where the President's steel pipes come in.

I should like to ask Mr. Newby more about the roughness factor. Has he tried lining his perspex ports with sandpaper (which may be analogous to the roughness of brickwork) and, if so, does it seem to make any difference?

Mr. Baker gave an excellent introduction to automatic control, which should not frighten anyone. He has been very humble, and has not stated, as Mr. Robertson pointed out recently, that this is probably the first gas-fired open-hearth furnace on which the gas flow has been linked to the roof temperature. Mr. Baker is very much to be congratulated on having achieved such a linkage. Many of us at the moment are trying to link roof temperature to oil flow, but we may have in future to link it to the gas flow, which is a rather more difficult problem.

I should like to ask Mr. Baker one or two questions about furnace-pressure control. He has been something of a pioneer in this direction also. He refused to believe that it was difficult and just did it. He placed his pressure pipe in the side wall of the furnace instead of in the roof, and at a very low level in the side wall, where one would almost expect a draught rather than a pressure. Does he think that this is the right place to fit the pressure pipe, or should it be in the centre of the roof ?

Secondly, does he think that one pipe is sufficient, or should not we have better control (though more complication) if we had two or three pipes ? Finally, does he think it important that the reading which we get should be an absolute reading, and therefore comparable from shop to shop, or is a relative reading sufficient ?

Mr. **F. L. Robertson** (Messrs. John Summers and Sons, Ltd.) : I should like to apply my remarks to my own particular branch of the trade. We must be very careful in what we do. We have called on outside scientists and tradesmen to help us, and they have done so ; and now we have to make sure that we know how to use what they have done for us.

I wish to begin by congratulating Mr. Baker very sincerely on the shop work which lies behind his paper. He has been a very strong moral support behind the work of my own firm for many years. The introduction of instruments has brought two new shop difficulties in its train. How can a melter use all the measurements that we have found to be quite clearly necessary for the economic and technological good of the steel and the furnace ? There are too many for him to attend to. Secondly, how can the co-ordination of all these measurements be planned and ordered before the charge, and, what is just as important, how can they be inspected after the charge ?

Mr. Baker has dealt with these difficulties, firstly by introducing automatic gear and secondly by starting with multiple-chart readings. In both cases he has not waited for the last word in engineering skill and invention, but has started straight away by using the bits and pieces that he found lying about the works ; a most commendable beginning. This kind of start very quickly leads the way. The automatic furnace no longer needs preaching about ; it is well on its way.

His other point, the multiple chart, is still in its infancy, and I should very much like to have his opinion on extending his multiple chart in a direction which I wish to suggest. The chart (Fig. B) shows in the top line the roof temperature right through the charge. The black line underneath it is the oil record of the charge. Then we have the steam flow for the charge, and below that the air flow, and then the CO_2 in the waste gases, the oxygen in the waste gases, and also the roof pressure. The roof pressure is intended to be kept within the two lines shown on the chart, but it is a manual operation, and the chart shows the best that we can do. On the left is the charging record, with the spar, lime, and ore feeds on the right ; on the right also are the time that the ore feed is allowed to start (shown by a darker line), the immersion temperature of the charge, the temperature ordered to correspond with the carbon content, the carbon drop, the sulphur drop, and the slag analysis when the feeding commenced and at tap.

These fifteen entries are all interrelated, and instructions about their interrelation are given before the charging starts. It is therefore necessary for the manager and melter to see clearly and early whether the orders have been carried out, or, if not, what prevented their execution. It is proposed that all these entries shall be made on the chart mechanically as they happen, the carbon and sulphur being punched on the card mechanically when reported.

My firm are actually discussing with B.I.S.R.A. the possibility of putting this into practice.

Dr. **A. H. Leckie** (British Iron and Steel Research Association) : I wonder whether the induction of a President from Scotland has anything to do with the appearance of Mr. Baker here this morning to show us how a complete set of instruments can be made from odds and ends at a very low cost. Mr. Baker is in an exceptional position, because both he and his father make a special hobby of instrument building, so that his example is not one that can be followed by everybody.

Those who are familiar with fine new instrument installations such as Mr. Senior's at Clydesdale and Mr. Jackson's at Appleby South may wonder whether there is much to be gained from the application of home-made instruments to an older shop, but Mr. Baker has shown us that it is just as feasible and just as important to instal instruments in the older and smaller shops. I hope that his paper will encourage steelmakers in Sheffield, South Wales, and other districts where there are small furnaces making special kinds of steel, and that they will see from it that the installation of instruments does not inevitably mean large expenditure.

Mr. Baker's installation now includes most of the instruments recommended by the Open-Hearth Instruments Sub-Committee, and I do not propose here to enter on a discussion of whether further instruments are needed, or whether they should all be put in at once or which should go in first, because such a discussion could easily last all day ; but there are a few specific questions which I should like to ask Mr. Baker.

First of all, does he consider that the method of operating automatic roof-pressure control, using the light butterfly valve admitting air to the stack, is suitable for routine control ? If so, it is to be preferred to the very expensive servo mechanisms operating heavy dampers, which are the usual means adopted today, but would this spoil the performance of a waste-heat boiler ?

Secondly, the reason for his use of the gas-reversing valve as a measuring orifice is appreciated, but does he meet with any difficulty from the tarring-up of the ring, which is really water-cooled ? He will be able to check that and know whether it is happening, because the meter will change its calibration. I should have thought that he could build-in an ordinary brick venturi, such as is now used for gas metering, in the short length of vertical main below the gas ring. Perhaps he will tell us whether he gets trouble with tarring-up when using his present method.

With regard to automatic crown-temperature control, Mr. Baker has now said that he has put in a derivative element to get over the difficulty of fluctuations when opening the doors. However, apart from the difficulty of sudden changes of roof temperature under these circumstances, it is interesting to know whether a simple proportional control would be sufficient, because we feel that some of the commercial makers of controllers may be over-anxious to attain a degree of stability by putting in derivatives which are unnecessary in open-hearth furnaces because of the large heat capacity of the structure.

I should like to draw attention to the very simple way in which Mr. Baker gets over the difficulty of three-shift maintenance of the immersion thermocouples. He does it by having enough couples prepared to last over the night shift, and so is able to get away with day-shift maintenance. They are not very expensive, so I do not see why that should not be done. By carrying a stock, thermocouple maintenance men are not required on the night shift. He is to be congratulated on the example which he has set to the small steelmakers.

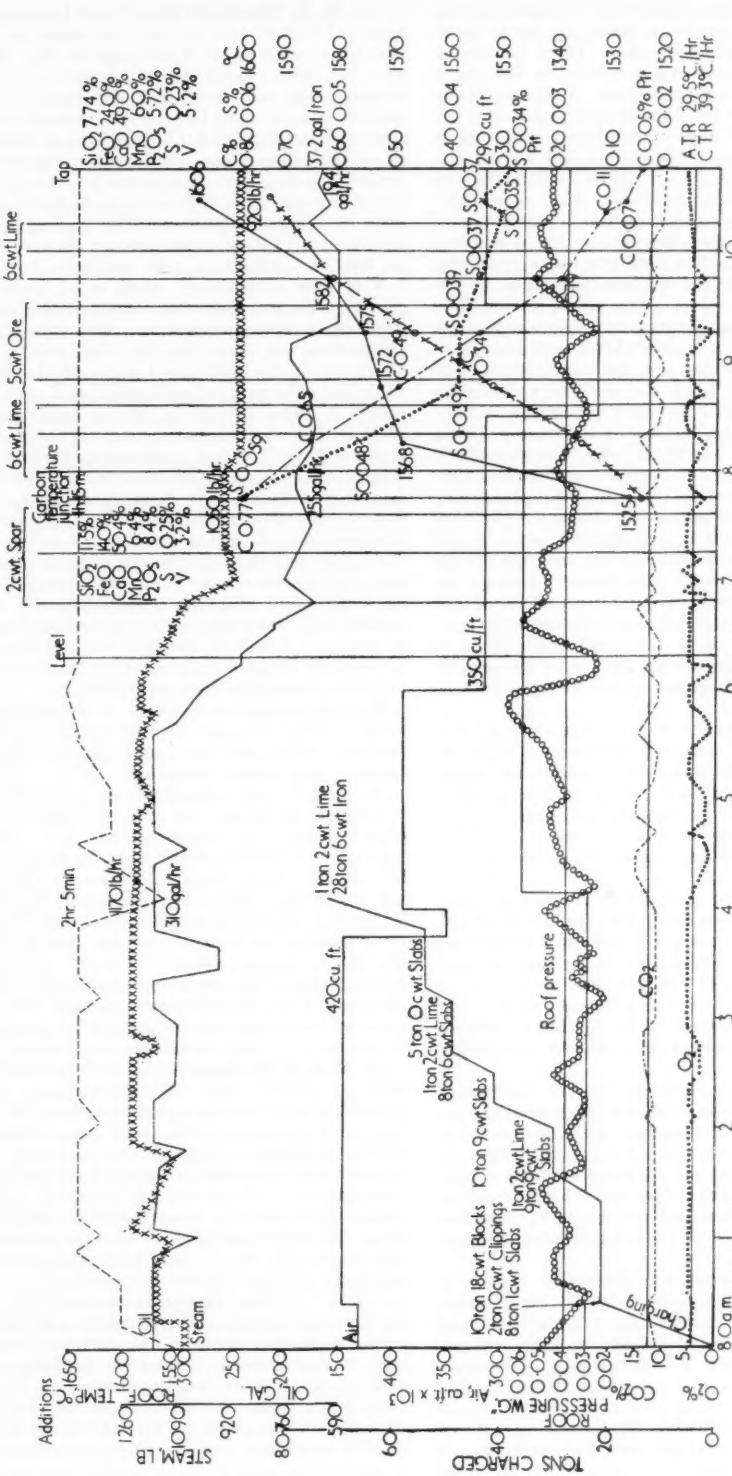


Fig. B—Example of multiple chart. (Cast L315 ; tap 6.40 p.m., 24th February, 1948)

Mr. Newby's work was undertaken because of the lack of data on friction factors in bends similar to those found in open-hearth-furnace uptakes. There are plenty of data in engineering textbooks on friction factors in ordinary bends and changes of section in pipe systems, but until this work there has been nothing on the rather complicated changes of section combined with bends which we get in open-hearth furnaces; and when some years ago we were asked to supply some data for the Government report "*The Efficient Use of Fuel*," all that we could do was to look up rough experimental data and make an estimate. Mr. Newby has now given us something reliable, based on more precise experiments.

On one point I think the explanation given in the paper is not sufficiently clear. The configuration used in these experiments would give two friction factors, one appropriate to the combined bend and change of section between the uptake and the port throat, and the other for the exit from the port to the furnace chamber. The latter will be unity when the furnace chamber is infinitely large, but not in the average open-hearth furnace or in Mr. Newby's model. Determination of these two friction factors therefore demands three static pressure measurements: one in the uptake, one in the port throat, and one in the furnace. I think Mr. Newby made all three measurements, but it is not clear from the paper that this was so, and we should like to know whether the friction factors to which he refers relate to the complete combined effect of the bend, change of section, and loss of velocity head going into the furnace, or to the bend and change of section only. In the latter case the figures are reasonable, but if they include the large loss going into the furnace they seem very low.

The object of this work, as Dr. Chesters and Mr. Newby have explained, is to try to obtain a high gas velocity in the port (in order to shorten the flame) without excessive gas pressure. It is always possible to increase the velocity by making the port smaller, but can it be done without additional pressure drop by making the port smaller and diminishing the friction losses in the bend?

There is another way of getting this very short flame. We all know that mixing can be obtained by high velocity, but it is also possible to get good and rapid mixing by diminishing the cross-sectional area of the port without increasing the velocity; in other words, using two or more small ports instead of one large one, so as to be able to use the same pressure. The combined velocity is not very high, but the small ports should give dimensionally a short flame.

Another way is by the modification of the Maerz port. If the air comes right in front of the gas, so that the gas has to cut through it, the gas and air then meet at right-angles and good mixing is obtained not through velocity but through the gas and air meeting at right-angles.

Mr. Newby's experiments have been most carefully done, and I can recommend them as being the first really precise figures which we have had on these peculiar shapes of bend.

I can comment very little on Mr. Muir's paper, as it deals more with intelligent works planning rather than pure research, but on reading it I am impressed by the immense amount of brickwork that we still find around ports in open-hearth furnaces. We have a strong feeling, from recent experimental work, that it would be possible to build a good open-hearth furnace with very much less brickwork in it than at present and get very good mixing. If we could do that we should eliminate many of the troubles to which Mr. Muir has referred. Let the fuel and air mix and the heat flow with as little physical obstruction as possible.

Dr. **D. F. Marshall** (Park Gate Iron and Steel Co., Ltd.): I should like to use the moral of Mr. Baker's paper to make a point on the paper by Mr. Muir. Anyone who has been closely associated with an open-hearth-furnace shop will have been tempted to keep an old furnace on for one, two, or three weeks longer at the end of a campaign, and if he has done so will undoubtedly have experienced the consequences of that course of action. He may have had a roof in on a charge, or have found himself with two or more furnaces off for repair with insufficient labour available to tackle them simultaneously. In most cases production over a period will be lost, not gained, as was originally hoped.

The only satisfactory method of approach to this problem, as Mr. Muir has clearly indicated, is to have a planned repair programme, but this planned repair programme at once implies the ability to forecast the lives of the individual parts of the furnace. Mr. Muir has obviously given a great deal of thought to the study of furnace records, to the types of refractories used in the various parts, and to the speeding up of repairs, all with a view to increasing furnace availability. I suggest, however, that there is another fundamental factor which has not been mentioned, and that is instrumentation, accompanied by the practice of strict furnace control, either manual or automatic. If at each open-hearth shop the question of instrumentation was tackled intensively from two angles, (i) instruments as such, and (ii) instrument-support organization, particularly on a 24-hr. basis, it would become practicable, as we have found in the last nine months, to practise a standard furnace control which furnacemen and staff generally can appreciate and follow.

The advantage of this type of technique is that the range of roof life and checker life for a given furnace becomes much narrower, and life forecasts and repair planning are greatly helped.

Mr. Muir's table of roof life on page 486 of his paper is almost identical with our experience, but we also found during the same period that our dolomite-consumption curve was almost the inverse of the roof-life curve. Does Mr. Muir consider that this factor influenced the dolomite-consumption figures shown in Table II? In this connection I should like to ask Mr. Muir whether he has yet decided what is the economic life of a dolomite hearth. Finally, it seems to be a direct challenge to research metallurgists and to furnace designers that the deposition of slag and its eventual removal from checkers or slag pockets should still play so prominent a part in determining furnace availability.

Mr. **R. E. H. Williams** (Wellman Smith Owen Engineering Corporation, Ltd.): There is perhaps no one in this country with a better experience than Mr. Muir of the matters which go to make up the very solid paper which he has presented. He has control not only of the maintenance and construction of these furnaces but also of the production of the refractory materials which go into them. That is on the whole a very fortunate position for him. He will probably not object to my saying that his paper is rather like a voice from the underworld telling us what the people up above do to him!

I have looked at this paper mainly from the point of view of one factor, *viz.*, the waste-gas velocities going through the hot parts of the furnace. Mr. Muir says that he uses about 3000–4000 bricklayer man-hours and about 8000 labourer man-hours to wreck and rebuild his furnaces. In a recent paper by Mr. Kilby, on the operation of open-hearth furnaces with coke-oven gas,* it was found that his silica consumption (producer-

* *Journal of The Iron and Steel Institute*, 1947, vol. 155, Jan., p. 3.

gas furnaces) was about 23–24 lb. of brick per ton of steel. At Consett it is, I think, 37–38 lb./ton. On the Redbourn furnaces referred to by Mr. Kilby the air and gas checkers lasted for two campaigns of 18–22 weeks per campaign; at Consett the time is up to 30 weeks. I do not know whether there is anyone here from Redbourn to confirm this, but I think that they used about 2400–2800 bricklayer man-hours on wrecking and rebuilding their furnaces, and approximately 3800 labourer man-hours, and that included wrecking the furnace and renewing one complete ring in each slag-pocket arch and full regenerator roofs.

I agree entirely with Mr. Muir when he says that it is not possible to make a direct comparison between one furnace plant and another, and I should not like him to think that I am making a comparison in any way invidious to Consett, but on looking at the drawing of the Consett furnace in Mr. Muir's paper I find that at both ends of the furnace there are two air uptakes, the combined cross-sectional area of which, scaling them roughly, seems to be about 12·4 sq. ft., while at Redbourn it is something like 48 sq. ft. On the assumption of $5\frac{1}{2}$ million B.Th.U. per ton of steel at Consett, I have tried to reckon approximately the relative waste-gas velocity at the top of their air uptakes under peak-flow conditions, and I think that it is about 29–30 ft./sec. At Redbourn I believe it is about half this value.

I wonder whether Mr. Muir and the fuel engineer and open-hearth manager at Consett would give us another short paper in the near future in which waste-gas velocities are compared with refractory consumptions in different parts of their furnaces. I am thinking not in terms of a laboratory or research-department experiment, but of a works test. If at Consett they have had integrating and recording gas- and air-flow meters during the last seven years, and if they have had frequent determinations of CO_2 and free oxygen in the waste gases, they might be able to calculate roughly the waste-gas flow. I am firmly of opinion that the greatest single factor leading to the destruction of the refractory materials in open-hearth furnaces is the waste-gas velocity with all that that implies.

I have read the papers by Mr. Newby and Mr. Baker with interest. I can pay Mr. Baker no better compliment than to say that he should be the chief beneficiary in Mr. Muir's will—if Mr. Muir ever has time to make one!

Mr. **M. W. Thring** (British Iron and Steel Research Association): If I refer only to Mr. Newby's paper no slight is intended to the other two, which are obviously of very great value, but I happen to be personally concerned in the work of Mr. Newby. The work that Dr. Chesters mentioned on the water model, and the work that Mr. Newby is doing with an air model, are really complementary lines of work, and it is in my opinion a very good thing that they are going on side by side in the steel industry, because the two kinds of model show different things. The air model is ideal for measuring mixing indices and for measuring pressure drops as discussed by Mr. Newby, but it is not nearly so good for showing flow patterns. On the other hand the water model which Dr. Chesters uses is very good indeed for showing flow patterns and is extremely interesting in that connection. I think it should be part of the education of every furnace designer to spend some hours watching the kind of flow patterns that are obtained in the model, because the whole model can be made transparent and the pattern can be seen in much more detail than is possible in an actual furnace; the flow pattern visible in those parts which can be seen in the actual furnace undoubtedly corresponds closely to the corresponding part of the pattern to the model.

I would also recommend that the air type of model, which is much easier to make and install, should be used much more widely in connection with new port designs. In fact, every time a furnace designer puts forward a new shape of port he should build an air model of it and test its resistance, and preferably also its mixing factors; because, although Mr. Newby did not mention it, since his paper was written he has developed a method of measuring mixing. I hope he will have the opportunity to report on that work in a year or two's time, because it is obviously, as he says, the logical continuation of the work on the gas port alone. Perhaps I can anticipate a little by saying that it is already confirming Dr. Leckie's work and other work, in showing that much more can be done by altering the air port than by altering the gas port. The main thing that can be done with the gas port is simply to put up the gas pressure, but with the air port there is much more latitude and by rearranging matters better mixing and also almost any sort of flame can be obtained; and it can be kept down or blown up as desired. It might even be a good plan in the refining period deliberately to blow the flame up and have air underneath, to have a more oxidizing atmosphere, simply keeping the flame on top to keep the roof temperature up; but that is looking rather far ahead.

Mr. Newby's paper suggests that there is not very much that can be done about the gas port to increase the velocity, except by increasing the pressure; but the ports mentioned by him, which had a kind of bell-mouth coming out of the gas port, we were frightened to recommend, because we could not be sure that the gas would not spread out and lose its velocity in the bell-mouth. But now that he has worked out a mixing index, a method of measuring mixing, it is worth testing that type of port to see whether it does not give better results than were anticipated when only the gas port could be studied. That will have to be done with the mixing model.

Finally, I do not think that it is beyond the bounds of possibility to make an air model of an oil-fired furnace. At first sight it seems impossible, because the oil is in droplets, and the process of heating up and evaporating the droplets and expansion of the steam, and so on, make it much more complicated than the gas-fired model, where preheated gas is blown into the furnace and it heats up a few hundred degrees when it burns. I think, however, that it is possible to make a model of an oil-fired furnace, because the oil is atomized with air or steam, and the weight of air or steam used is an appreciable fraction of the weight of oil, so that a mixture of air or steam and oil can simply be regarded as a heavy gas. It should be possible, therefore, to do similar mixing experiments using a heavy gas in a model, and something on those lines may be possible unless, as Dr. Chesters suggests, oil becomes of less interest and there is a swing back to producer gas.

Mr. **H. Parnham** (General Refractories, Ltd.): I very much appreciate the paper by Mr. Muir, and I should like to ask him whether he considers that metal-plate joints between chemically bonded bricks in back walls are really necessary, and if so whether the extra cost involved is offset by an increase in the life. I should like also to ask him whether in all-basic construction he prefers a chrome-magnesite brick (unfired) to a magnesite-chrome brick (unfired), from the point of view of life.

CORRESPONDENCE

Professor **R. J. Sarjant** (Sheffield University) wrote: Mr. Baker is to be congratulated on the writing in a relatively short paper of an account of a development which when analysed in terms of modern requirements is

a very noteworthy achievement. The work commenced as a pioneer effort when instrumentation as it is now known was in its infancy. I saw some of the earliest of the trials in the application of gas- and air-flow measurement and in the application of furnace-draught control, and I marvelled at the ingenuity shown in the construction of the earliest prototypes of the equipment. Mr. R. C. Baker's modesty precludes him from mentioning the important contributions made in these valuable developments by his father, Mr. S. E. Baker. The open-hearth furnace is an appliance which has been generally looked upon as too complicated, both in its construction and its operation, to be amenable to control as an automatic unit. Mr. Baker's company have virtually proved the invalidity of this contention. Certainly, so far as the heating arrangements are concerned, the achievements described amount to the provision of an automatic unit, and meet conditions which might well, on *a priori* grounds, be regarded as the ideal requirements for controlling a melting unit. Thus there is a primary master controller in linking the critical effective temperature, that of the roof, to the rate of heat input. Both are the supremely important factors in open-hearth heating. The secondary controller is in effect a master control of combustion and draught, giving what the fuel engineer should aim for in all fuel-burning installations, namely an automatic system of balanced draught and air/gas ratio control. At the same time the essential requirements of a process which demands a high standard of skill from the operative is borne in mind in making the indications of the controllers readily apparent to the furnaceman. The value of this was early demonstrated in the indicators of air-, producer-gas-, and coke-oven-gas flow illustrated in Fig. 4 of the paper. It has also been suggested as an essential requirement of a successful system of instrumentation that there must be a limit to the number and complication of the instruments employed. Quite truly the open-hearth furnace is a very important and critical unit in steelworks plant. A relatively few individuals can readily save or waste a large amount of money in a short time in its operation. Therefore economically probably a considerable multiplication of instruments may be justified, provided that they can be properly maintained. If at the same time in achieving an effective control a limited number of master controllers is used, then the result is all to the good. In the arrangements described it is to be noted with interest that control of the regenerator temperatures is regarded as secondary, not in the sense that it is regarded as of any less importance than it was so considered in some of the earlier systems of open-hearth instrumentation, but in that the interpretation of the readings of the instruments is dealt with by the shop management rather than by the operative. In the same manner it may be concluded from the author's statements that the use of the immersion couple is also so regarded, for the operator makes use of the instrument only when metallurgical considerations show need for information to be obtained on the temperature of the bath.

I know of no paper on the subject into which has been crowded into so small a space so much valuable information, often the result of years of painstaking and careful experiments. It should stimulate discussion on the features which constitute the ideal means of automatically controlling the fuel aspects of open-hearth operation, encourage the makers of the instruments to take heart of grace and emulate the achievements which have been described, and finally dispose of the contentions of that rapidly diminishing band of unbelievers in the truth that the operation of an open-hearth furnace can be made a science rather than an art. The paper finally leaves one with the thought that the many other aspects of furnace operation, the balancing of the air/gas ratio to give ideally desirable compositions of the atmosphere to suit particular stages of melting and refining, the systematic checking of draughting conditions by draught surveys, the assessment of the radiative capacity of the flame, should all be regarded as secondary features of control, coming within the special sphere of the more expert elements of the furnace management, and not necessarily considered as matter which the furnaceman himself is required to have in mind. It suggests, too, that the indications of the instruments might well be made the subject of operational research whereby valuable data may be obtained leading to progress in the subject of furnace design.

Dr. **M. C. Marsh** (Cambridge Instrument Co., Ltd.) wrote: I have been very interested to read the full account of Mr. Baker's valuable work on the instrumentation of open-hearth furnaces, especially as the firm with which I am connected has supplied the Fery telescopes which he has used. These have been practically standard instruments, except that they have been shorn of their external fittings and care has been taken to ensure that the external supports were co-axial with the optical system.

Encouraged by what Mr. Baker has done, we have now pushed the design one stage further and have recently produced an experimental Fery telescope specially for use on open-hearth furnaces. The thermocouple with its target plate has been redesigned so as to give a much more rapid response and has been compensated for ambient temperature. A water-cooling system is built into the case of the instrument and provision has been made for an air blast to keep the front window clean.

All the features of this instrument have been tried out, as far as possible, in our own laboratory and it is hoped to carry out tests under working conditions in the very near future.

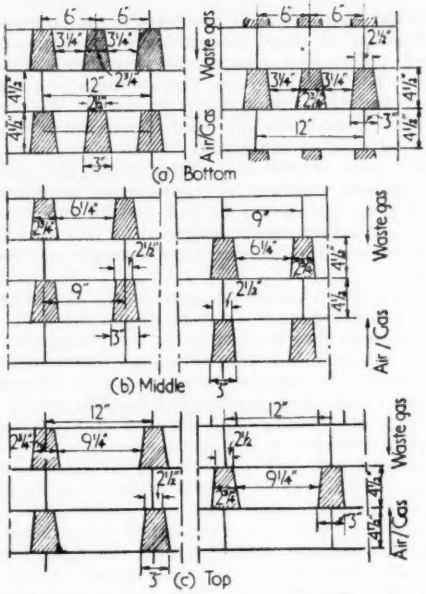
Mr. **R. Whitfield** (The Incandescent Heat Co., Ltd., Smethwick) wrote: Thanks are due to the Consett Iron Co., Ltd., for enabling Mr. Muir's valuable paper to be given to the Institute.

I have had some practical success in building checkers of standard side-arch bricks, 12 × 4½ × 3–2½ in., and 9 × 4½ × 3–2½ (*see* Fig. C.). With this arrangement the checkers can be arranged in three zones, corresponding roughly to different rates of expansions of air, or gas, passing upwards, and the varying rates of contraction as the waste gases proceed downwards. Also, the hot waste gases proceed down through a series of flues having **V**-shaped sides, and the air passing upwards comes against the bottoms of the side-arch bricks making it more turbulent and thus there is generally a better exchange of heat.

Against such an arrangement is the resulting loss in weight, although this is of the order of only 10%. There is, however, a small increase of area in favour of heat transfer. A difference of opinion as to whether weight or surface is the more important has always existed. With the configuration suggested the balance is in favour of side-arch construction.

I am wholly in favour of insulating regenerators and, further, of sealing the outer surfaces with hot silicate of soda, thus preventing the ingress of dust into the porous insulating bricks, which gradually destroys the insulating properties.

Some mention was made in the paper by Mr. Muir of the possible use of liquid fuel. In general, future open-hearth furnaces will make provision for liquid and/or gaseous fuels. At a recent meeting of the Iron and Steel Engineers Group, I raised the question of steam *versus*



	(a)	(b)	(c)
Weight of bricks, lb./cu. ft. of regen.vol.	59·5	39·7	29·8
Flue area, sq. in.	10·56	39	85·6

Dimensions of Brick, in.	Weight of Brick, lb.
12 × 4½ × 3	12·18
9 × 4½ × 3	9·15
12 × 4½ × 3–2½	11·16
9 × 4½ × 3–2½	8·39

Basis : 130 lb./cu. ft.
Ratio of side arch to square : 91·6%

Fig. C—Arrangements of checkers in three zones, using standard side-arch bricks

air atomization, I myself being strongly in favour of air. Some facts, figures, and arguments were given which need not be repeated. I raise the question again because of the economic availability of commercial oxygen and its certain increasing use, particularly because of the higher temperatures available. Is it practicable to consider atomizing liquid fuel by pressure oxygen ? There are, I think, possibilities in this direction. Air and/or oxygen atomization provides a valuable flexibility in temperature and atmosphere.

Mr. Newby's work is, so far as I know, quite a new approach to gas-port design, *viz.*, the application of thermodynamics. It was quite exhilarating to read this paper and to listen to the discusson.

Owing to the erosion of refractory materials the original factors in the calculations may become very different ; for instance, a glazed port will have very different characteristics from a newly built one. The Reynolds number, Re, is proportional to area, velocity, and pressure, and inversely proportional to viscosity. Assuming a flow of a volume, then, the Re tends to alter because of the changing area, velocity, and pressure ; probably, however, the change will not be significant. On the other hand Re may be very different for the directional flow of air and gas one way, and carbon dioxide, nitrogen, and H_2O, the other. The viscosity of gases varies very much and increases with temperature. Therefore a compromise must be made. This is a nice mathematical problem. The initial experiments on the wooden model are well worth practical demonstration, because many factors at high temperatures are unknown ; this knowledge of high-temperature thermophysics will be of great value to science and industry.

A study of Chapter V of McAdam's work on heat transmission* will be very fruitful in considering the problem of ports and flow of gases, but certain modifications must be introduced owing to the high temperatures and surfaces under these conditions.

AUTHORS' REPLIES

Mr. **D. C. Muir** replied : I should like to thank Dr. Chesters for his remarks and to endorse all he said about the work of the All-Basic Furnace Sub-Committee. I hope that those who are installing these furnaces will make sure that all their operational data are available because it is upon such data that we shall largely depend for any alterations in design.

With regard to Dr. Chesters' question about silica roofs, I would say that a silica roof should be patched as long as it can be done without wasting any time. Normally this takes place on a Saturday afternoon, but with the continuous working week it will mean taking the furnace off, and the number of times that that can be done boils down to a simple question of cost and time.

The manner of determining the life of the roof, whether in weeks, output, or heats, depends largely upon the kind of furnace in question. It is possible to compare only similar furnaces operating under similar conditions, and as only the men who work a furnace know how hard it is being driven, we think the method we have adopted of reckoning the furnace life in weeks up to the first major patch at least enables a comparison to be made of the quality of the bricks and the efficiency of operation.

In reply to Dr. Leckie, we are now operating some 150-ton oil-fired furnaces which have more or less unrestricted ends. We get a great deposition of iron oxide in the regenerators of these furnaces and I have wondered whether the amount of brickwork at the ends of the 75-ton furnaces, which absorbs quite a lot of the iron oxide, may be of some use after all.

Dr. Marshall asks why we have not mentioned instrumentation. We have started to put full instrumentation on our 150-ton furnaces during the last two years but we have not yet sufficient data to make any correlation with furnace life. He asked what I might consider the economic life of a dolomite hearth. I have wondered about that myself and that is why we took out the time lost on the individual furnaces due to bad bottoms on seven basic furnaces. The oldest hearth was a very bad one, but the next oldest, aged 15 years, was as good, from that point of view, as the hearth which was one year old. We could find no straight-line correlation, over a period of five years, between the age of the hearth and the time lost on bad bottoms. We are therefore forced to the conclusion that a furnace hearth is good, *i.e.*, economic, as long as the time lost on that hearth does not consistently exceed the shop average.

Concerning the remarks by Mr. Williams, we have had considerable wear on the furnace ends and that is why we introduced the chrome-magnesite panels, by means of which we have almost eliminated that trouble. So far as the life of the regenerators is concerned, there are other factors in addition to the actual velocity of the gases going down the checkers. A furnace charging 60–70% of hot metal cannot be compared with one which charges that proportion of scrap. We are taking steps to introduce unrestricted uptakes in our furnaces, but the wear on the furnace ends, uptakes, and regenerators, depends also upon the amount of slag carried forward by the furnace gases and the rate of furnace operation.

In reply to Mr. Parnham I can say that at the present time we are using metal plates in the back lining, and we find that they do give and have given an increase of two or three weeks in the life, but we are devoting some time to finding a substitute for metal plates

* McAdam, "Heat Transmission." London and New York, 1942 : McGraw-Hill Book Co., Inc.

as they are a nuisance to the bricklayers. We think that the metal can be introduced in some kind of cement, and experiments are being carried out with that object in view. Mr. Parnham also asks whether I should like unfired chrome-magnesite bricks or unfired magnesite-chrome bricks in the all-basic furnace construction. I should be inclined to prefer the magnesite-chrome bricks in the roof and the chrome-magnesite bricks in the back lining.

Mr. **M. P. Newby** replied: I should like to endorse Dr. Chesters' remark that recirculation, where a jet enters a closed chamber, is an almost incurable phenomenon. We have found the same thing in some present work on the side-blown converter. He asks whether we carried out any experiments on the actual roughness of the ports. We did not. Our experiments were self-consistent and were all made on the same material. We think it probable, at any rate, that the relations which exist between our various models would also exist between similar constructions in actual furnace material. Moreover, the limits of roughness which occur on the surface of refractories are quite small in comparison with the total dimensions of the chamber and, although they are no doubt larger than occur in our model, we think that they exert only a small effect on the actual friction factor of the port. Figure 11 of my paper, which compares model results with the actual furnace trials, shows that this factor is not a very large one.

Dr. Leckie asks a question about the points at which we measured the pressure in determining friction factors. In considering the inflowing gas, we measured the pressure between a point well down in the uptake and one in the throat. For the outflowing gas the pressure is measured in the uptake and in the furnace chamber, the pressure in the chamber being nearly uniform for flow in this direction.

We found that our friction factors were small, and this seems to be a good example of where actual measurements carried out in a model are superior to estimates based on measurements carried out with conventional bends with possibly long pipes up and down stream.

It is quite true that mixing in a port does not depend only on the velocity, and one can have several ports of smaller area with the same pressure drop and the same velocity and obtain better mixing. This is the line of research on which we are now working, and which Mr. Thring has mentioned. This new research is also concerned with the actual design and relative position of the ports with respect to each other, and not merely with the velocity produced in them.

I should like to thank Mr. Thring for his suggestion that we might try well-rounded ports in the new experiments which we are doing to determine the mixing. We shall certainly do this.

Mr. **R. C. Baker** replied: I should like to thank Dr. Chesters, Mr. Robertson, and Dr. Leckie for their most complimentary remarks. Dr. Chesters asked about the position of the pressure pipe in the side wall, and whether that was the right position for it. This point was chosen in our case purely for convenience, but judging by the sting at the top of the door—I know that this is very controversial—it appears to be satisfactory, and this is confirmed by spot tests with a micro-manometer. As for the use of more than one pipe I think the subject is sufficiently complicated with one. Then there is the question of whether an absolute reading of furnace pressure is necessary. We started with a furnace-pressure reading which was not an absolute reading, but I now consider that it is necessary to get an absolute figure if possible.

Mr. Robertson said that instruments brought two shop difficulties in their train: (i) How can the melter use all the measurements necessary? (ii) how can the co-ordination of these measurements be planned and ordered before the charge and inspected after the charge? The answer to the first question is automatic control, but there is another point there. We consider that when using automatic control particular attention should be paid to the layout of the instrument panel from the point of view of the furnaceman, and that only the minimum number of instruments necessary for control purposes should be put on the main furnace panel, a secondary panel being used for any instruments which concern the melting-shop manager or the fuel engineer.

With regard to his second question, the idea of extending the combined chart is excellent, and the work which he has already done in plotting out these results by hand is most valuable, but it is important that items which only directly concern the melter should be recorded on this chart, and any further information which is of interest to the melting-shop manager and fuel engineer should be recorded on a separate chart.

Finally, I am very pleased to hear that a firm of instrument makers has had the initiative to tackle the problem of the multiple chart.

In reply to Dr. Leckie, the method of operating automatic roof-pressure control, using the light butterfly valve admitting air to the stack, appears to be satisfactory but was devised mainly to overcome the difficulties of moving a heavy damper. With a waste-heat boiler it would not be satisfactory, but most waste-heat-boiler dampers are of the butterfly type and are easily moved, and we use a similar Hopkinson regulator on a waste-heat boiler.

He asked whether the gas-reversing valves tar-up. The answer is only to the extent of $\frac{1}{8}$–$\frac{1}{4}$ in. on the inside diameter of the orifice. There is no great change in the calibration throughout the week.

He also asked if we could not use a venturi below the gas valve to measure gas flow. Our only reason for not doing so is that we have no experience in measuring gas flow across a venturi, and the gas valve has been used as an orifice for a long period and is satisfactory. At the moment a model of this gas valve has been sent to one of the instrument makers for calibration for the new furnace which is being installed.

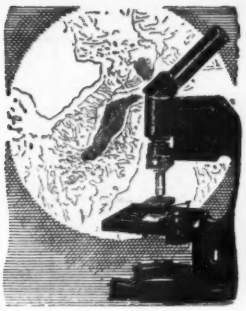
Finally, with regard to automatic crown temperature control, Dr. Leckie asked whether a simple proportional control would be sufficient. We have at present only experience of a floating control with a derivative function added.

Professor Sarjant has commented on the paper very fully, and as he has been working in collaboration with us for a number of years, our ideas are similar. He raises the question of automatic gas/air ratio; we have no experience of this at present, and although suitable instruments are on order we are in some doubt as to the effect of air inleakage during a heat and during the life of the furnace.

I agree with Dr. Marsh on the importance of the optical and mechanical axes of the radiation pyrometer being the same, but I have found that the speed of response of the old type of Fery pyrometer is quite sufficient.

With the old type of Fery and the Robertson type of housing, it is necessary only to take out the plug for the electrical connections and the Fery can be taken out of the tube both for cleaning the glass and for removing obstructions from the sight hole. With the new type of Fery pyrometer it would appear to be necessary to break both water and air connections to do this, which would probably take a considerable time instead of the few minutes as at present.

B. I. S. R. A.



BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Fatigue Tests on Crankshaft Steels

By P. H. Frith, A.Met., F.I.M.

Part I—THE EFFECT OF NITRIDING ON THE FATIGUE PROPERTIES OF A CHROMIUM–MOLYBDENUM STEEL

SYNOPSIS

The tests on the solid test-pieces showed that after nitriding for 10, 22, or 72 hr. at 485° C. the fatigue fractures commenced in the vicinity of the junction between the case and the core, but with the nitrided, hollow-with-oil-hole specimens, the fractures commenced on the surface of the nitrided case.

From the test results obtained it was calculated that by nitriding crankshafts and airscrew shafts for 10 instead of for 72 hr. at 485° C. a reduction in the fatigue limit of approximately 0·7% would be obtained for the sections of the components which were approximately 3·0 in. dia. without any form of stress concentration, whilst the fatigue limit of the oil-hole sections of the components would be slightly increased. Therefore, from a fatigue point of view, it appeared that the 10-hr. nitriding treatment at 485° C. was more suitable for crankshafts and airscrew shafts, than the 72-hr. nitriding treatment at 485° C. The depth of the nitrided case, as determined by a fracture test after the 10-hr. nitriding treatment, was 0·004 in., and this appeared to be quite adequate for crankshafts and airscrew shafts, from a wear-resisting point of view.

It seemed highly probable that by nitriding crankshafts and airscrew shafts for 10 hr. at 485° C. instead of for 72 hr. at 485° C. the grinding operation after nitriding might be replaced by a honing or lapping operation. This appeared to be a possibility because after nitriding for the shorter period the surface hardness was increased, and the amount of distortion and growth obtained during nitriding will most likely be reduced. The substitution of a honing or lapping operation, for the grinding operation for finishing nitrided engine components, would eliminate the possibility of grinding cracks being formed, and would therefore simplify the manufacturing process.

INTRODUCTION

DURING the last 15 years a number of papers has been published giving the results of fatigue tests (carried out on the Wöhler and the Haigh types of machines) on various steels after nitriding, and a summary of the majority of these papers published before 1936 was prepared by Sutton.[2]

These papers showed that :

(*a*) The fatigue limit obtained on a Wöhler type of machine (which produces reversed bending stresses) using solid specimens without any form of stress concentration, was increased by nitriding.[2, 3, 4, 6, 7, 8, 9, and 11]

(*b*) The percentage increase in the fatigue limit due to nitriding solid specimens without any form of stress concentration, was considerably more for specimens tested on the Wöhler type of machine than for specimens tested on the Haigh type of machine (which gives push-pull loading).[2, 11]

(*c*) With reversed bending stresses, the fatigue fractures of solid specimens without any form of stress concentration commenced in the vicinity of the junction between the case and the core.[2, 3, 10, and 11]

(*d*) The stress concentration caused by a notch or fillet of small radius, was considerably reduced under reversed bending stresses by nitriding.[2, 6, 7, 10, and 11]

(*e*) The corrosion-fatigue limit, determined with reversed bending stresses and river water, was considerably increased by nitriding.[5, 6, 9, and 11]

It appeared from these papers that no fatigue tests had been carried out on steels in the nitrided

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Mr. Frith is with the Bristol Aeroplane Co., Ltd. Bristol.

Table I

CHEMICAL COMPOSITION AND HEAT-TREATMENTS OF THE CR–MO STEEL

Test Series	Diameter of bar,	Chemical Composition	Types of Test Carried out	Heat-Treatment			Remarks
				After Cutting Bars to Test Length and Before Machining	After Rough Machining	After Finish Turning	
A	1¼	As in F	Tensile, Izod, and fatigue	900° C. (1 hr. soak), oil quenched 580° C. (1 hr. soak), oil quenched	Nil	Nil	
B	1¼	As in C	Tensile, Izod, and fatigue	900° C. (1 hr. soak), oil quenched 600° C. (1 hr. soak), oil quenched	Nil	Nil	
C	1¼	C, 0·28%; Si, 0·26%; Mn, 0·55%; S, 0·014%; P, 0·018%; Ni, 0·17%; Cr, 3·09%; Mo, 0·51%	Izod and fatigue	900° C. (1 hr. soak), oil quenched 600° C. (1 hr. soak), oil quenched	*Izod test-pieces* stabilized for 8 hr. at 500° C., tinned, nitrided for 10 hr. at 485° C. *Fatigue test-pieces* stabilized for 8 hr. at 500° C.	*Fatigue test-pieces* nitrided for 10 hr. at 485° C.	The fatigue tests were carried out with the test-pieces in the "as nitrided" condition
D	1¼	As in C	Izod and fatigue	900° C. (1 hr. soak), oil quenched 600° C. (1 hr. soak), oil quenched	*Izod test-pieces* stabilized for 8 hr. at 500° C., tinned, nitrided for 22 hr. at 485° C. *Fatigue test-pieces* stabilized for 8 hr. at 500° C.	*Fatigue test-pieces* nitrided for 22 hr. at 485° C.	The fatigue tests were carried out with the test-pieces in the "as nitrided" condition
E	1¼	As in C	Fatigue	900° C. (1 hr. soak), oil quenched 600° C. (1 hr. soak), oil quenched	*Fatigue test-pieces* stabilized for 8 hr. at 500° C.	*Fatigue test-pieces* nitrided for 22 hr. at 485° C.	After nitriding and before testing, the diameter of the stressed section of the fatigue test-pieces was reduced 0·004 in. by grinding
F	1¼	C, 0·20%; Si, 0·23%; Mn, 0·56%; S, 0·024%; P, 0·014%; Ni, 0·12%; Cr, 2·91%; Mo, 0·42%	Izod and fatigue	900° C. (1 hr. soak), oil quenched 580° C. (1 hr. soak), oil quenched	*Izod test-pieces* stabilized for 8 hr. at 500° C., tinned, nitrided for 72 hr. at 485° C. *Fatigue test-pieces* stabilized for 8 hr. at 500° C.	*Fatigue test-pieces* nitrided for 72 hr. at 485° C.	The fatigue tests were carried out with the test-pieces in the "as nitrided" condition
G	1¼	As in C	Izod and fatigue	900° C. (1 hr. soak), oil quenched 600° C. (1 hr. soak), oil quenched	*Izod test-pieces* stabilized for 8 hr. at 500° C., tinned, nitrided for 72 hr. at 485° C. *Fatigue test-pieces* stabilized for 8 hr a 500° C.	*Fatigue test-pieces* nitrided for 72 hr. at 485° C.	The fatigue tests were carried out with the test-pieces in the "as nitrided" condition

Notes. (1) The test-pieces for test series C to E and G were nitrided in the laboratory furnace using a Nichrome nitriding box (inside dimensions 6½ × 4 × 14½ in., dissociation approximately 12%). After the test-pieces had been cleaned in trichlorethylene and placed on a jig in the box to prevent warping and to ensure uniform circulation of the gas round the test-pieces, the lid of the box was fastened in position and the box was put in the furnace at atmospheric temperature. The ammonia gas was then passed through the box for 1 hr. before switching on the current supply, and 4 hr. were allowed for the box and test-pieces to reach the nitriding temperature. The nitriding time stated in the above Table was the time the box was at temperature before the current supply was finally switched off, and the box was allowed to cool in the furnace with the gas passing through for a further period of approximately 16 hr. The test-pieces for test series F were nitrided in a production Birlec furnace with crankshafts.

(2) The microstructures obtained for the 1¼ and 1½-in. dia. bars after the oil hardening and tempering treatments revealed a moderately coarse sorbitic structure as shown in Figs. 4 and 5.

Table II

MECHANICAL PROPERTIES AND DEPTH OF NITRIDED CASE OF THE CR–MO STEEL

Test Series	Diameter of Bar, in.	Tensile Properties						Brinell Hardness (on surface of heat-treated bar)	Izod Impact Value, ft.lb.	V.P.N. on Surface of Nitrided Fatigue Test-Pieces	Depth of Case on Nitrided Fatigue Test-Pieces (Measured by Fracture Test), in.
		Tons/sq. in.				Elongation, %	Reduction of Area, %				
		Limit of Proportionality	0·1% Proof Stress	0·2% Proof Stress	Max. Stress						
A	$1\frac{5}{16}$	41·0	53·7	55·5	61·8	18·5	68·0	302	79–74	...	...
B	$1\frac{1}{2}$	33·0	50·6	52·6	61·2	21·0	72·0	302	102–103–108	...	...
C	$1\frac{1}{2}$	...	...	...	...	...	...	...	80–96–102	976	0·004
D	$1\frac{1}{2}$	...	...	...	...	...	...	...	96–102–98	770	0·006
F	$1\frac{5}{16}$	...	...	...	...	...	...	...	76–81	882	0·013
G	$1\frac{1}{2}$	...	...	...	...	...	...	...	89–96–95	730	0·013

Notes. The tensile tests were carried out using the test-piece type D, Fig. 3 (gauge length polished longitudinally with "00" polishing paper), and a Huggenberger extensometer (1 division = 0·000334 in.)
The izod tests were carried out using the test-piece type E, Fig. 3

condition, with torsional stresses superimposed on a bending stress, and no fatigue tests appeared to have been carried out to determine the effect of nitriding on the stress concentration caused by an oil hole. An investigation was therefore planned to determine the fatigue properties of a chromium–molybdenum steel in the un-nitrided and nitrided conditions, using solid specimens (type A) and hollow specimens with an hole oil (type B), under the stress conditions of reversed bending (stress condition 1), reversed torsion (stress condition 2), or various combinations of reversed bending and torsion (stress condition 3), and the nitriding treatments chosen were 10 hr., 22 hr., or 72 hr. at 485° C.

When this investigation was commenced the nitriding treatment generally recommended for this type of steel was 72 hr. at approximately 500° C., and the fatigue data which were available had been obtained after nitriding for 48 to 96 hr. There appeared to be no published data giving the effect of nitriding for shorter periods at approximately 500° C., and, therefore, fatigue tests after nitriding for 10 and 22 hr. at 485° C. were included in the present investigation.

DETAILS OF MATERIAL USED

The material was supplied in the form of $1\frac{5}{8}$ and $1\frac{1}{2}$-in. dia. rolled bars to specification D.T.D. 306, and the chemical composition, heat-treatments, and tensile and izod properties, are given in Tables I and II, whilst the depth/hardness curves obtained by taper grinding specimens 0·625 in. square, after nitriding, are shown in Fig. 1.

FATIGUE TESTS

The fatigue tests were carried out at approximately

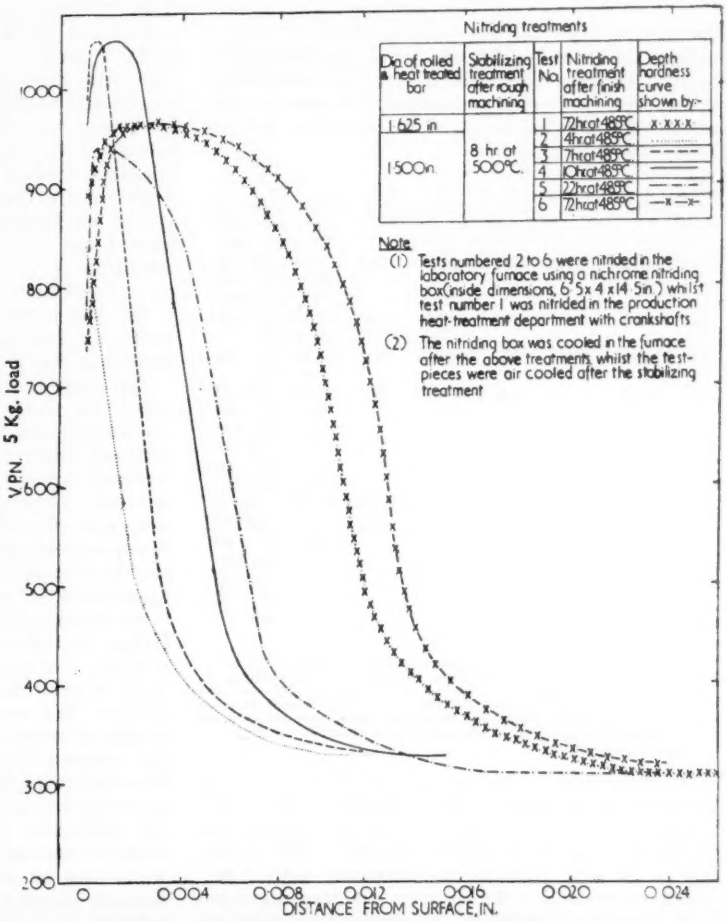
Nitriding treatments
Dia of rolled & heat treated bar
Stabilizing treatment after rough machining
Test No.
Nitriding treatment after finish machining
Depth hardness curve shown by:-
1·625 in.
1·500 in.
8 hr. at 500°C.
1 72hr at 485°C
2 4hr at 485°C
3 7hr at 485°C
4 10hr at 485°C
5 22hr at 485°C
6 72hr at 485°C
Note
(1) Tests numbered 2 to 6 were nitrided in the laboratory furnace using a nichrome nitriding box (inside dimensions, 6·5 x 4 x 14·5 in.) whilst test number 1 was nitrided in the production heat-treatment department with crankshafts
(2) The nitriding box was cooled in the furnace after the above treatments, whilst the test-pieces were air cooled after the stabilizing treatment
V.P.N. 5 Kg. load
1000
900
800
700
600
500
400
300
200
0
0·004
0·008
0·012
0·016
0·020
0·024
DISTANCE FROM SURFACE, IN.

Fig. 1—Depth-hardness curves (Cr–Mo steel)

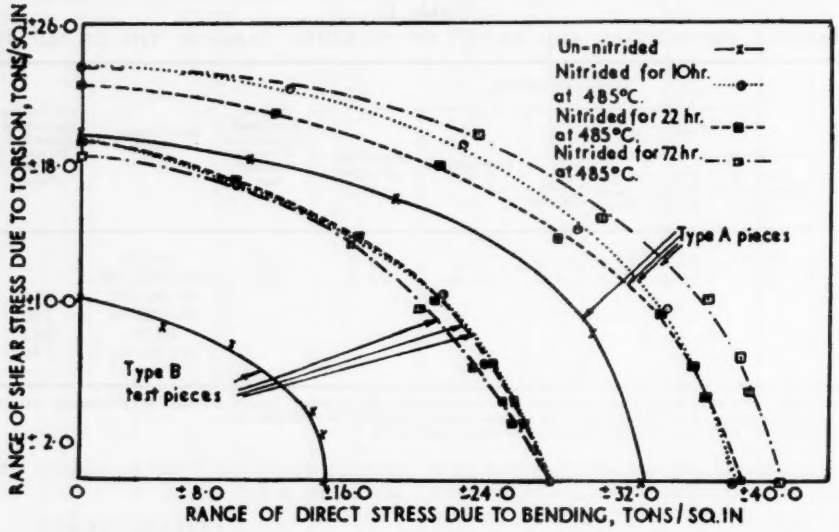

Fig. 2—Fatigue test results obtained on Cr–Mo steel (max. tensile strength 61·5 tons/sq. in.)

2100 cycles/min. on the combined-stress fatigue machine shown in Fig. 14, which was designed at the National Physical Laboratory,[1] and then modified in our laboratory to test specimens of 0·600 in. dia. instead of 0·300 in. dia., and the following fatigue limits were determined :

Test Series	(1)	(2)	(3)	(4)	(5)
A	Solid	Nil	Nil	Nil	0°, 15°, 20° 36′, 30°, 45°, 60°, 75°, and 90°
B	Hollow, with oil hole	Nil	Nil	Nil	0°, 15°, 20° 36′, 30°, 45°, 60°, 75°, and 90°
C	Solid	10	0·004	Nil	0°, 30°, 45°, 60°, and 90°
C	Hollow, with oil hole	10	0·004	Nil	0°, 30°, 45°, 60°, and 90°
D	Solid	22	0·006	Nil	0°, 15°, 20° 36′, 30°, 45°, 60°, 75°, and 90°
D	Hollow, with oil hole	22	0·006	Nil	0°, 15°, 20° 36′, 30°, 45°, 60°, 75°, and 90°
E	Solid	22	0·006*	0·004	0°, 45°, and 90°
F	Solid	72	0·013	Nil	0°, 15°, 20° 36′, 30°, 45°, 60°, 75°, and 90°
G	Hollow, with oil hole	72	0·013	Nil	0°, 15°, 20° 36′, 30°, 45°, 60°, 75°, and 90°

(1)—Type of Test-Piece (see Fig. 3)
(2)—Time of Nitriding at 485° C., hr.
(3)—Depth of Nitriding Case (Measured by Fracture Test), in.
(4)—Amount Ground off Test-Piece Diameter after Nitriding, in.
(5)—Value of θ. (When $\theta = 0°$, reversed bending stresses are obtained, whilst when $\theta = 90°$ reversed torsional stresses are obtained, and for the remaining angles the stresses are partly reversed torsional and partly reversed bending)

* Before grinding

On completion of the turning operations, the solid test-pieces were polished longitudinally, with " 00 " polishing paper, on the portion to be stressed, and test series C to F were then nitrided. The hollow test-pieces were polished longitudinally with " 00 " paper before drilling the oil-holes, and then test series C, D, and G were nitrided. No surface treatment was carried out on the fatigue specimens for test series C, D, F, and G after the nitriding operation (*i.e.*, the tests were carried out in the " as-nitrided " condition), but for test series E the portion of the specimens to be stressed was finished turned to 0·604 in. dia., and after nitriding was finished by grinding, with a wheel having a 2·0-in. radius, to 0·600 in. dia. During this final grinding operation no special precautions were taken, and the tests were carried out with the test-pieces in the " as-ground " condition (*i.e.*, no further surface treatment was carried out with " 00 " polishing paper).

The test results obtained are shown in Table III, whilst the fatigue limits are shown in Table IV and plotted in Fig. 2.

The angle the fracture made with the longitudinal axis of the test-pieces, in the un-nitrided or nitrided conditions, was 90° for the specimens tested with reversed bending stresses, and the angle decreased as torsional stresses were superimposed on the bending stresses. It was found that the angles of fracture were not affected by the nitriding treatments, and the specimens shown in Figs. 10 and 11 were typical for the test-pieces of types A and B tested in the un-nitrided or nitrided conditions.

An examination of the fractures obtained on the fatigue test-pieces showed that for the un-nitrided test-pieces of types A and B and the nitrided specimens of type B, no white areas—indicating that the fracture had commenced below the surface of the specimen—were visible, and a typical fracture for the nitrided type B specimen is shown in Fig. 9. However, with the nitrided type A specimens, white areas were clearly visible, as shown in Fig. 8, on all the specimens except a few tested with reversed torsional stresses ($\theta = 90°$), and the absence of the white area on these specimens was probably due to damage caused to the fractured faces by the constant rubbing of the surfaces before the machine cut out.

DISCUSSION OF RESULTS

EFFECT OF NITRIDING AND TESTING IN THE "AS NITRIDED" CONDITION, ON THE FATIGUE PROPERTIES OF SOLID TEST-PIECES

After the N.P.L. combined-stress fatigue machine had been modified, as shown in Fig. 14, to test specimens of 0·600 in. dia. instead of 0·300 in. dia., static and dynamic calibration tests were carried out.

On completion of these tests, reversed bending fatigue tests were commenced on the un-nitrided type A test-pieces, using the modified combined-stress machine, whilst reversed bending fatigue tests were also carried out on a similar steel, using a Wöhler machine and the type C specimens shown in Fig. 3. The latter test-pieces were machined from test lengths cut from 1-in. dia. rolled bar of the following composition:

C, %	Si, %	Mn, %	S, %	P, %	Ni, %	Cr, %	Mo, %
0·24	0·16	0·55	0·014	0·016	0·12	3·18	0·53

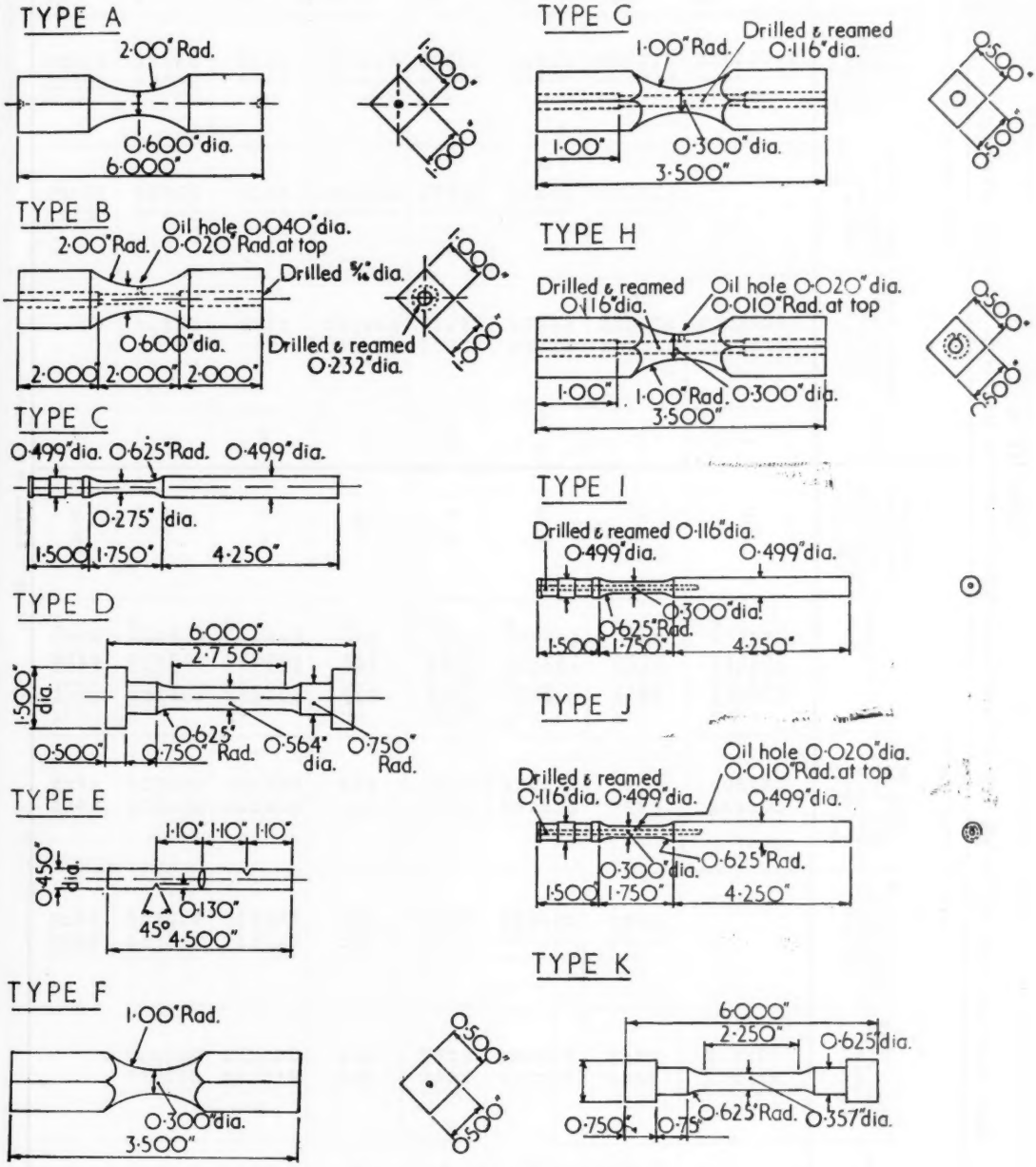

Fig. 3—Dimensions of test-pieces

Table III (*a*)

TEST RESULTS OBTAINED ON THE COMBINED-STRESS FATIGUE MACHINE WITH UN-NITRIDED CR–MO STEEL TEST-PIECES

Solid Test-Pieces (type A)						Hollow-with-oil-hole Test-Pieces (type B)					
Value of θ	Range of Direct Stress Due to Bending, tons/sq. in.	Range of Shear Stress Due to Torsion, tons/sq. in.	Range of Maximum Shear Stress Induced in Specimen tons/sq. in.	No. of Cycles	Estimated Fatigue Limit in Terms of Maximum Shear Stress, tons/sq. in.	Value of θ	Range of Direct Stress Due to Bending, tons/sq. in.	Range of Shear Stress Due to Torsion, tons/sq. in.	Range of Maximum Shear Stress Induced in Specimen, tons/sq. in.	No. of Cycles	Estimated Fatigue Limit in Terms of Maximum Shear Stress, tons/sq. in.
0°	±34·84	..	±17·42	489,652 (B)	±16·48	0°	±17·27	..	± 8·63	283,883 (B)	± 7·23
	±34·40	..	±17·20	620,774 (B)			±15·74	..	± 7·87	575,160 (B)	
	±33·90	..	±16·95	894,204 (B)			±15·47	..	± 7·73	375,911 (B)	
	±33·40	..	±16·70	2,463,415 (B)			±15·22	..	± 7·61	488,926 (B)	
	±33·15	..	±16·57	2,710,790 (B)			±14·97	..	± 7·48	895,892 (B)	
	±32·97	..	±16·48	14,565,117 (UB)			±14·77	..	± 7·38	1,124,474 (B)	
							±14·47	..	± 7·23	31,786,029 (UB)	
							±14·47	..	± 7·23	33,990,452 (UB)	
15°	±32·73	± 4·39	±16·94	250,774 (B)	±16·43	15°	±15·46	± 2·07	± 8·00	297,488 (B)	± 7·37
	±32·49	± 4·35	±16·81	730,089 (B)			±14·73	± 1·97	± 7·63	686,282 (B)	
	±31·98	± 4·29	±16·56	3,909,293 (B)			±14·48	± 1·94	± 7·49	1,107,458 (B)	
	±31·74	± 4·25	±16·43	14,941,349 (UB)			±14·24	± 1·91	± 7·37	24,350,037 (UB)	
							±14·01	± 1·88	± 7·25	43,242,441 (UB)	
							±14·01	± 1·88	± 7·25	36,141,133 (UB)	
20° 36′	±32·59	± 6·12	±17·40	302,741 (B)	±16·56	20° 36′	±15·09	± 2·83	± 8·06	213,409 (B)	± 7·50
	±32·21	± 6·05	±17·21	902,841 (B)			±14·29	± 2·68	± 7·63	480,843 (B)	
	±31·73	± 5·96	±16·95	904,824 (B)			±14·29	± 2·68	± 7·63	838,747 (B)	
	±31·49	± 5·92	±16·81	1,069,221 (B)			±14·04	± 2·64	± 7·50	21,228,027 (UB)	
	±31·25	± 5·88	±16·69	2,361,463 (B)			±13·55	± 2·55	± 7·23	33,601,528 (UB)	
	±31·01	± 5·83	±16·56	21,143,287 (UB)							
30°	±30·95	± 8·96	±17·92	830,016 (B)	±17·21	30°	±14·53	± 4·19	± 8·39	519,129 (B)	± 7·87
	±29·91	± 8·66	±17·32	1,986,969 (B)			±14·09	± 4·07	± 8·13	398,316 (B)	
	±29·80	± 8·60	±17·21	15,081,510 (UB)			±13·87	± 4·00	± 8·01	1,534,559 (B)	
	±29·22	± 8·43	±16·87	11,913,451 (UB)			±13·64	± 3·94	± 7·87	32,881,860 (UB)	
							±13·20	± 3·81	± 7·62	42,823,316 (UB)	
45°	±26·37	±13·18	±18·64	198,380 (B)	±18·06	45°	±12·58	± 6·29	± 8·90	323,304 (B)	± 8·14
	±25·72	±12·86	±18·18	1,474,200 (B)			±12·22	± 6·11	± 8·64	409,376 (B)	
	±25·54	±12·76	±18·06	17,960,180 (UB)			±11·87	± 5·93	± 8·40	1,083,919 (B)	
							±11·69	± 5·84	± 8·27	640,070 (B)	
							±11·51	± 5·75	± 8·14	39,817,865 (UB)	
							±11·14	± 5·57	± 7·88	33,464,480 (UB)	
60°	±20·10	±17·40	±20·10	637,000 (B)	±18·45	60°	± 9·54	± 8·26	± 9·54	340,197 (B)	± 8·82
	±19·89	±17·22	±19·89	525,420 (B)			± 9·06	± 7·85	± 9·06	958,417 (B)	
	±19·63	±17·00	±19·63	962,500 (B)			± 8·94	± 7·74	± 8·94	1,402,177 (B)	
	±19·51	±16·89	±19·51	901,040 (B)			± 8·82	± 7·64	± 8·82	21,842,872 (UB)	
	±18·52	±16·04	±18·52	1,300,040 (B)							
	±18·45	±15·97	±18·45	41,312,040 (UB)							
75°	±10·67	±19·90	±20·61	270,340 (B)	±19·05	75°	± 5·38	±10·03	±10·40	341,730 (B)	± 9·29
	±10·40	±19·41	±20·09	353,920 (B)			± 5·12	± 9·55	± 9·89	689,610 (B)	
	±10·02	±18·73	±19·35	762,860 (B)			± 5·00	± 9·33	± 9·66	555,011 (B)	
	± 9·96	±18·58	±19·24	1,925,560 (B)			± 4·87	± 9·09	± 9·40	1,051,840 (B)	
	± 9·90	±18·47	±19·12	3,142,020 (B)			± 4·81	± 8·98	± 9·29	21,859,923 (UB)	
	± 9·86	±18·39	±19·05	29,835,120 (UB)							
90°	..	±20·61	±20·61	471,940 (B)	±19·88	90°	..	±11·46	±11·46	1,371,082 (B)	±10·50
	..	±20·36	±20·36	1,821,680 (B)			..	±11·09	±11·09	3,455,000 (B)	
	..	±20·11	±20·11	2,352,420 (B)			..	±10·61	±10·61	5,239,162 (B)	
	..	±19·88	±19·88	36,099,140 (UB)			..	±10·50	±10·50	23,769,709 (UB)	
							..	±10·37	±10·37	34,034,099 (UB)	

(B) = Broken; (UB) = Unbroken

Table III (*b*)

TEST RESULTS OBTAINED ON THE COMBINED-STRESS FATIGUE MACHINE WITH CR–MO STEEL TEST-PIECES NITRIDED FOR 10 OR 22 HR. AT 485° C.

Solid Test-Pieces (type A)							Hollow-with-oil-hole Test-Pieces (type B)					
Condition of Test-Piece	Value of θ	Range of Direct Stress Due to Bending, tons/sq. in.	Range of Shear Stress Due to Torsion, tons/sq. in.	Range of Maximum Shear Stress Induced in Specimen, tons/sq. in.	No. of Cycles	Estimated Fatigue Limit in Terms of Maximum Shear Stress, tons/sq. in.	Value of θ	Range of Direct Stress Due to Bending, tons/sq. in.	Range of Shear Stress Due to Torsion, tons/sq. in.	Range of Maximum Shear Stress Induced in Specimen, tons/sq. in.	No. of Cycles	Estimated Fatigue Limit in Terms of Maximum Shear Stress, tons/sq. in.
Nitrided for 10 hr. at 485° C.	0°	±41·45 ±40·54 ±40·05 ±39·36 ±38·41 ±38·19	.. ..	±20·73 ±20·27 ±20·02 ±19·68 ±19·20 ±19·10	4,398,195 (B) 2,530,511 (B) 3,166,222 (B) 11,231,311 (B) 34,814,114 (B) 64,030,691 (UB)	±19·10	0°	±28·96 ±28·24 ±27·76 ±27·51	.. ..	±14·48 ±14·12 ±13·88 ±13·75	758,027 (B) 1,550,742 (B) 1,270,149 (B) 21,969,930 (UB)	±13·75
	30°	±35·91 ±35·09 ±34·69 ±34·30 ±33·89 ±33·47	±10·37 ±10·13 ±10·02 ± 9·90 ± 9·78 ± 9·66	±20·73 ±20·26 ±20·02 ±19·80 ±19·56 ±19·32	4,026,566 (B) 9,506,740 (B) 4,635,166 (B) 26,003,492 (B) 70,645,443 (UB) 34,318,294 (UB)	±19·56	30°	±24·65 ±24·23 ±23·89 ±23·60	± 7·12 ± 6·99 ± 6·88 ± 6·81	±14·23 ±13·99 ±13·80 ±13·63	233,249 (B) 114,429 (B) 353,101 (B) 26,959,365 (UB)	±13·63
	45°	±31·11 ±30·14 ±29·19 ±28·87	±15·55 ±15·07 ±14·60 ±14·43	±22·00 ±21·31 ±20·64 ±20·41	1,771,189 (B) 12,062,212 (B) 4,336,145 (B) 56,451,077 (UB)	±20·41	45°	±22·17 ±21·49 ±21·34 ±21·14 ±21·14 ±20·47	±11·09 ±10·75 ±10·68 ±10·57 ±10·57 ±10·23	±15·67 ±15·20 ±15·09 ±14·94 ±14·94 ±14·47	155,475 (B) 1,806,826 (B) 12,935,520 (B) 31,376,690 (UB) 37,806,560 (UB) 31,972,708 (UB)	±14·94
	60°	±23·36 ±23·36 ±23·02 ±23·02 ±22·69 ±22·46 ±22·35 ±22·23	±20·24 ±20·24 ±19·94 ±19·94 ±19·64 ±19·45 ±19·35 ±19·25	±23·36 ±23·36 ±23·02 ±23·02 ±22·69 ±22·46 ±22·35 ±22·23	780,942 (B) 688,881 (B) 2,339,397 (B) 4,971,579 (B) 16,022,216 (B) 18,682,798 (B) 34,496,340 (B) 83,248,844 (UB)	±22·23	60°	±17·97 ±16·51 ±16·28 ±16·03 ±15·92	±15·56 ±14·30 ±14·09 ±13·89 ±13·79	±17·97 ±16·51 ±16·28 ±16·03 ±15·92	133,942 (B) 293,562 (B) 2,208,308 (B) 3,655,449 (B) 77,789,349 (UB)	±15·92
	90°	.. ..	±24·94 ±24·48 ±24·04 ±23·81 ±23·58	±24·94 ±24·48 ±24·04 ±23·81 ±23·58	760,580 (B) 578,709 (B) 2,695,605 (B) 75,819,875 (UB) 67,826,329 (UB)	±23·81	90°	.. ..	±21·01 ±20·29 ±20·05 ±19·79 ±19·32	±21·01 ±20·29 ±20·05 ±19·79 ±19·32	2,547,535 (B) 777,273 (B) 3,952,468 (B) 36,247,064 (UB) 40,327,728 (UB)	±19·79
Nitrided for 22 hr. at 485° C.	0°	±39·62 ±39·12 ±38·65 ±38·43 ±38·17	.. ..	±19·81 ±19·56 ±19·33 ±19·21 ±19·09	1,569,494 (B) 2,321,815 (B) 4,070,433 (B) 29,901,530 (UB) 24,323,481 (UB)	±19·21	0°	±29·46 ±29·46 ±28·97 ±27·96 ±27·71 ±27·43 ±26·42	.. ..	±14·73 ±14·73 ±14·48 ±13·98 ±13·85 ±13·72 ±13·21	52,466 (B) 90,043 (B) 82,527 (B) 174,272 (B) 2,501,210 (B) 32,721,342 (UB) 21,125,789 (UB)	±13·72
	15°	±39·57 ±38·69 ±38·39 ±37·72 ±37·46 ±37·20 ±36·70 ±36·29	± 5·30 ± 5·18 ± 5·14 ± 5·05 ± 5·02 ± 4·98 ± 4·92 ± 4·86	±20·49 ±20·03 ±19·87 ±19·52 ±19·40 ±19·26 ±19·00 ±18·79	695,529 (B) 2,091,667 (B) 2,164,009 (B) 2,891,586 (B) 2,209,527 (B) 2,318,997 (B) 9,241,673 (B) 54,569,393 (UB)	±18·79	15°	±28·00 ±27·74 ±27·51 ±26·76 ±26·52 ±25·99 ±25·77	± 3·75 ± 3·72 ± 3·68 ± 3·59 ± 3·55 ± 3·48 ± 3·45	±14·50 ±14·36 ±14·24 ±13·85 ±13·73 ±13·45 ±13·34	69,623 (B) 59,556 (B) 97,274 (B) 114,007 (B) 306,429 (B) 385,837 (B) 39,225,992 (UB)	±13·34
	20° 36′	±37·70 ±36·31 ±36·06 ±35·81 ±35·57	± 7·08 ± 6·82 ± 6·77 ± 6·73 ± 6·68	±20·13 ±19·40 ±19·26 ±19·12 ±19·00	1,349,510 (B) 3,955,936 (B) 3,925,979 (B) 4,033,359 (B) 23,538,732 (UB)	±19·00	20° 36′	±26·42 ±26·17 ±25·71 ±25·48 ±25·48 ±25·23 ±25·23 ±25·00 ±25·00	± 4·96 ± 4·92 ± 4·83 ± 4·79 ± 4·79 ± 4·74 ± 4·74 ± 4·70 ± 4·70	±14·11 ±13·98 ±13·73 ±13·61 ±13·61 ±13·47 ±13·47 ±13·35 ±13·35	67,355 (B) 169,273 (B) 96,565 (B) 66,640 (B) 34,366,241 (UB) 19,128,538 (UB) 24,375,845 (UB) 21,032,301 (UB) 20,549,735 (UB)	±13·47
	30°	±38·74 ±36·21 ±35·31 ±34·93 ±34·49 ±34·04 ±33·68	±11·18 ±10·45 ±10·20 ±10·09 ± 9·96 ± 9·83 ± 9·72	±22·36 ±20·90 ±20·39 ±20·16 ±19·92 ±19·65 ±19·44	921,999 (B) 4,521,306 (B) 8,519,361 (B) 17,048,169 (B) 23,534,733 (B) 7,233,864 (B) 60,200,633 (UB)	±19·44	30°	±25·54 ±24·85 ±24·44 ±24·22 ±24·01 ±24·01	± 7·37 ± 7·18 ± 7·05 ± 6·99 ± 6·93 ± 6·93	±14·75 ±14·35 ±14·11 ±13·94 ±13·86 ±13·86	72,318 (B) 153,285 (B) 6,685,302 (B) 132,724 (B) 23,339,571 (UB) 20,455,784 (UB)	±13·86
	45°	±29·85 ±29·56 ±29·20 ±28·83 ±28·53 ±28·16 ±27·80	±14·92 ±14·78 ±14·60 ±14·42 ±14·27 ±14·08 ±13·90	±21·10 ±20·90 ±20·65 ±20·36 ±20·17 ±19·91 ±19·65	2,016,018 (B) 1,476,693 (B) 8,794,170 (B) 5,117,031 (B) 11,015,907 (B) 23,092,416 (B) 111,769,995 (UB)	±19·65	45°	±22·34 ±21·64 ±20·94 ±20·78 ±20·62 ±19·93	±11·17 ±10·82 ±10·47 ±10·39 ±10·30 ± 9·97	±15·80 ±15·30 ±14·80 ±14·70 ±14·58 ±14·10	270,798 (B) 1,283,900 (B) 1,236,985 (B) 52,924,400 (UB) 39,189,524 (UB) 59,874,401 (UB)	±14·70
	60°	±22·37 ±21·37 ±21·11 ±20·90	±19·36 ±18·50 ±18·28 ±18·10	±22·37 ±21·37 ±21·11 ±20·90	2,594,400 (B) 14,724,066 (B) 9,722,232 (B) 68,868,771 (UB)	±20·90	60°	±17·96 ±16·51 ±16·28 ±16·03	±15·56 ±14·30 ±14·09 ±13·89	±17·96 ±16·51 ±16·28 ±16·03	296,309 (B) 658,606 (B) 595,313 (B) 35,736,000 (UB)	±16·03
	75°	±12·47 ±12·10 ±11·58 ±11·45 ±11·31 ±11·26	±23·27 ±22·56 ±21·61 ±21·35 ±21·10 ±20·99	±24·08 ±23·38 ±22·37 ±22·12 ±21·85 ±21·75	1,108,260 (B) 3,956,764 (B) 14,962,074 (B) 26,947,215 (B) 38,965,773 (B) 104,144,010 (UB)	±21·75	75°	± 9·69 ± 9·31 ± 9·25 ± 9·18	±18·08 ±17·38 ±17·27 ±17·13	±18·72 ±17·98 ±17·87 ±17·73	681,314 (B) 1,154,371 (B) 29,582,305 (B) 49,918,864 (UB)	±17·73
	90°	.. ..	±24·92 ±23·70 ±22·97 ±22·72	±24·92 ±23·70 ±22·97 ±22·72	591,905 (B) 9,790,253 (B) 11,937,730 (B) 72,589,562 (UB)	±22·72	90°	.. ..	±20·91 ±20·66 ±19·68 ±19·45	±20·91 ±20·66 ±19·68 ±19·45	758,125 (B) 758,542 (B) 2,015,000 (B) 40,216,000 (UB)	±19·45

(B) = Broken ; (UB) = Unbroken

Table III (c)

TEST RESULTS OBTAINED ON THE COMBINED-STRESS FATIGUE MACHINE WITH CR–MO STEEL TEST-PIECES NITRIDED FOR 72 HR. AT 485° C. AND WITH TEST-PIECES NITRIDED FOR 22 HR. AT 485° C. AND GROUND

Solid Test-Pieces (type A)							Hollow-with-oil-hole Test-Pieces (type B)					
Condition of Test-Piece	Value of θ	Range of Direct Stress Due to Bending, tons/sq. in.	Range of Shear Stress Due to Torsion, tons/sq. in.	Range of Maximum Shear Stress Induced in Specimen, tons/sq. in.	No. of Cycles	Estimated Fatigue Limit in Terms of Maximum Shear Stress, tons/sq. in.	Value of θ	Range of Direct Stress Due to Bending, tons/sq. in.	Range of Shear Stress Due to Torsion, tons/sq. in.	Range of Maximum Shear Stress Induced in Specimen, tons/sq. in.	No. of Cycles	Estimated Fatigue Limit in Terms of Maximum Shear Stress, tons/sq. in
Nitrided for 72 hr. at 485° C.	0°	±44·06	..	±22·03	597,334 (B)	±20·35	0°	±28·97	..	±14·48	76,714 (B)	±13·72
		±43·56	..	±21·78	811,716 (B)			±27·96	..	±13·98	94,864 (B)	
		±42·06	..	±21·03	1,583,572 (B)			±27·71	..	±13·86	106,775 (B)	
		±41·56	..	±20·78	1,696,922 (B)			±27·71	..	±13·86	110,178 (B)	
		±41·1	..	±20·55	1,833,384 (B)			±27·43	..	±13·72	20,589,360 (UB)	
		±40·7	..	±20·35	17,372,660 (UB)			±27·18	..	±13·59	41,984,144 (UB)	
	15°	±42·88	± 5·74	±22·19	882,853 (B)	±20·14	15°	±26·76	± 3·59	±13·85	61,399 (B)	±13·09
		±42·49	± 5·69	±21·99	839,257 (B)			±25·78	± 3·46	±13·34	520,264 (B)	
		±41·52	± 5·56	±21·49	1,363,240 (B)			±25·54	± 3·42	±13·22	316,355 (B)	
		±41·30	± 5·53	±21·38	1,482,740 (B)			±25·29	± 3·39	±13·09	27,006,377 (UB)	
		±41·04	± 5·50	±21·24	1,736,166 (B)			±25·01	± 3·35	±12·94	39,524,764 (UB)	
		±40·30	± 5·40	±20·86	1,851,080 (B)							
		±39·82	± 5·33	±20·61	2,721,180 (B)							
		±39·40	± 5·28	±20·40	4,831,120 (B)							
		±39·08	± 5·24	±20·23	5,915,560 (B)							
		±38·91	± 5·21	±20·14	30,847,740 (UB)							
	20° 36′	±40·56	± 7·62	±21·66	1,724,520 (B)	±20·47	20° 36′	±25·71	± 4·83	±13·73	41,547 (B)	±13·21
		±40·18	± 7·55	±21·46	2,004,660 (B)			±25·23	± 4·74	±13·48	62,250 (B)	
		±39·69	± 7·46	±21·20	2,324,560 (B)			±25·00	± 4·69	±13·35	94,689 (B)	
		±38·83	± 7·30	±20·74	3,555,440 (B)			±24·74	± 4·65	±13·21	22,310,528 (UB)	
		±38·33	± 7·20	±20·47	20,137,040 (UB)			±24·74	± 4·65	±13·21	25,239,575 (UB)	
	30°	±38·83	±11·21	±22·41	1,361,500 (B)	±20·97	30°	±24·22	± 6·99	±13·98	144,068 (B)	±13·22
		±38·28	±11·08	±22·13	1,508,640 (B)			±23·77	± 6·86	±13·72	121,806 (B)	
		±38·01	±10·97	±21·94	1,252,480 (B)			±23·34	± 6·74	±13·48	306,257 (B)	
		±37·87	±10·85	±21·69	2,298,660 (B)			±23·12	± 6·67	±13·35	124,691 (B)	
		±37·12	±10·72	±21·43	2,229,360 (B)			±22·90	± 6·61	±13·22	20,363,472 (UB)	
		±36·68	±10·58	±21·18	2,938,600 (B)			±22·90	± 6·61	±13·22	35,921,201 (UB)	
		±36·32	±10·49	±20·97	17,867,360 (UB)							
	45°	±32·87	±16·44	±23·24	846,720 (B)	±21·33	45°	±21·16	±10·58	±14·96	112,356 (B)	±14·00
		±32·58	±16·29	±23·04	827,960 (B)			±20·11	±10·06	±14·22	100,333 (B)	
		±31·85	±15·92	±22·52	1,108,660 (B)			±19·97	± 9·98	±14·13	265,344 (B)	
		±31·20	±15·60	±22·06	3,583,160 (B)			±19·79	± 9·89	±14·00	23,711,941 (UB)	
		±30·71	±15·36	±21·71	5,301,660 (B)			±19·46	± 9·73	±13·76	23,696,739 (UB)	
		±30·35	±15·17	±21·45	7,013,020 (B)							
		±30·17	±15·09	±21·33	30,873,360 (UB)							
	60°	±24·25	±20·98	±24·25	1,239,280 (B)	±23·01	60°	±16·66	±14·43	±16·66	242,126 (B)	±15·80
		±23·52	±20·35	±23·52	2,273,320 (B)			±16·16	±14·40	±16·16	120,195 (B)	
		±23·26	±20·14	±23·26	4,650,660 (B)			±16·04	±13·86	±16·04	3,719,376 (B)	
		±23·01	±19·91	±23·01	22,461,320 (UB)			±15·95	±13·81	±15·95	839,426 (B)	
								±15·80	±13·68	±15·80	20,607,278 (UB)	
								±15·45	±13·39	±15·45	20,191,296 (UB)	
	75°	±12·80	±23·89	±24·73	599,200 (B)	±23·27	75°	± 9·62	±17·95	±18·58	129,217 (B)	±17·62
		±12·54	±23·39	±24·23	2,184,140 (B)			± 9·49	±17·72	±18·33	148,288 (B)	
		±12·40	±23·13	±23·95	2,968,840 (B)			± 9·37	±17·49	±18·10	112,080 (B)	
		±12·16	±22·69	±23·49	5,921,720 (B)			± 9·25	±17·26	±17·87	111,527 (B)	
		±12·05	±22·49	±23·27	33,923,960 (UB)			± 9·12	±17·01	±17·62	31,857,209 (UB)	
	90°	..	±25·12	±25·12	250,880 (B)	±23·75	90°	..	±19·84	±19·84	647,743 (B)	±18·68
		..	±24·73	±24·73	724,640 (B)			..	±19·18	±19·18	939,621 (B)	
		..	±24·47	±24·47	1,925,420 (B)			..	±18·94	±18·94	941,694 (B)	
		..	±24·22	±24·22	2,035,600 (B)			..	±18·68	±18·68	26,589,541 (UB)	
		..	±23·98	±23·98	2,560,140 (B)							
		..	±23·75	±23·75	24,519,040 (UB)							
Nitrided for 22 hr. at 485° C. and then 0·004 in. Ground off the Diameter	0°	±41·46	..	±20·73	830,446 (B)	±19·31						
		±38·86	..	±19·43	4,140,631 (B)							
		±38·63	..	±19·31	37,236,903 (UB)							
		±38·39	..	±19·20	68,093,247 (UB)							
	45°	±30·33	±15·17	±21·44	2,180,341 (B)	±20·26						
		±29·66	±14·83	±20·97	4,640,203 (B)							
		±28·99	±14·50	±20·50	12,822,754 (B)							
		±28·65	±14·32	±20·26	65,541,016 (UB)							
	90°	..	±24·27	±24·27	988,388 (B)	±23·46						
		..	±23·57	±23·57	5,206,798 (B)							
		..	±23·46	±23·46	55,208,450 (UB)							
		..	±23·46	±23·46	50,852,024 (UB)							

(B) = Broken ; (UB) = Unbroken

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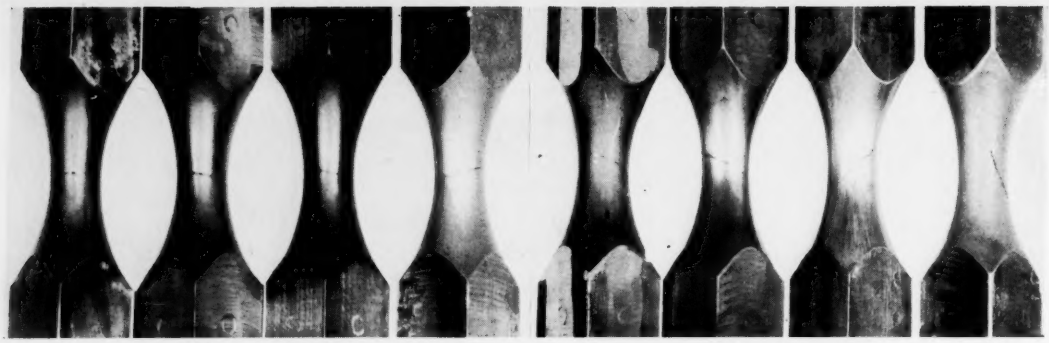
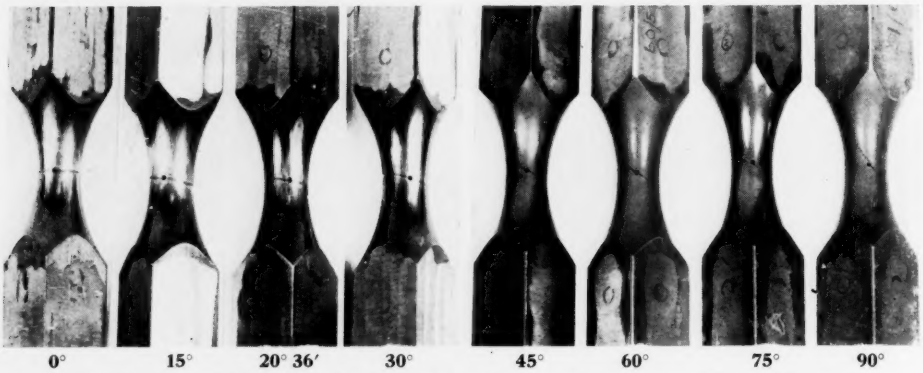


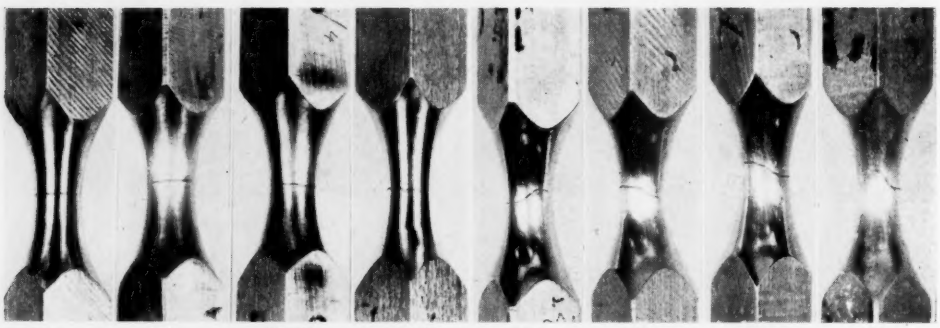
θ 0° 15° 20° 36′ 30° 45° 60° 75° 90°

Fig. 10—Angle of fracture of solid test-pieces, type A ; Cr-Mo steel



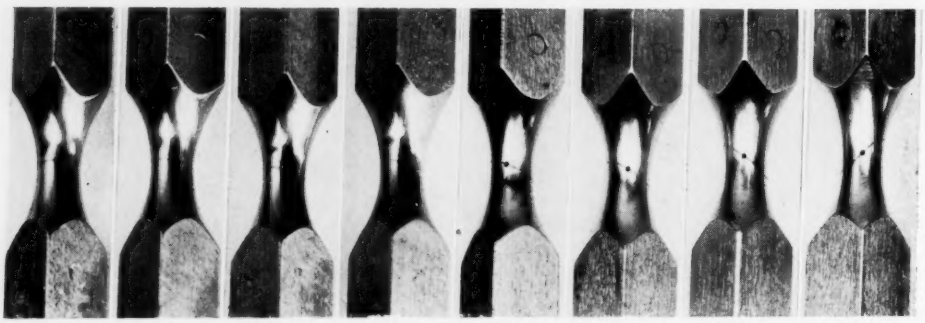
θ 0° 15° 20° 36′ 30° 45° 60° 75° 90°

Fig. 11—Angle of fracture of hollow-with-oil-hole test-pieces, type B ; Cr-Mo steel



θ 0° 15° 20° 36′ 30° 45° 60° 75° 90°

Fig. 12—Angle of fracture of solid test-pieces, type F ; Ni-Cr-Mo steel



θ 0° 15° 20° 36′ 30° 45° 60° 75° 90°

Fig. 13—Angle of fracture of hollow-with-oil-hole test-pieces, type H ; Ni-Cr-Mo steel

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Table IV

FATIGUE LIMITS OBTAINED ON THE COMBINED-STRESS FATIGUE MACHINE (CR–MO STEEL)

Solid 0·600 in. dia. (type A, *see* Fig. 3)							Hollow-with-oil-hole 0·600 in. O.D. (type B, *see* Fig. 3)						
Test Series	Condition	Value of θ	Ratio of Applied Twisting Moment to Bending Moment—Tan θ	Fatigue Limits, tons/sq. in.			Test Series	Condition	Value of θ	Ratio of Applied Twisting Moment to Bending Moment—Tan θ	Fatigue Limits, tons/sq. in.		
				Range of Direct Stress Due to Bending	Range of Shear Stress Due to Torsion	Range of Maximum Shear Stress Induced in Specimen					Range of Direct Stress Due to Bending	Range of Shear Stress Due to Torsion	Range of Maximum Shear Stress Induced in Specimen
A	Un-nitrided	0°	0	±32·97	..	±16·48	B	Un-nitrided	0°	0	±14·47	..	± 7·23
		15°	0·2679	±31·74	± 4·25	±16·43			15°	0·2679	±14·24	± 1·91	± 7·37
		20° 36′	0·3759	±31·01	± 5·83	±16·56			20° 36′	0·3759	±14·04	± 2·64	± 7·50
		30°	0·5774	±29·80	± 8·60	±17·21			30°	0·5774	±13·64	± 3·94	± 7·87
		45°	1·0000	±25·54	±12·76	±18·06			45°	1·0000	±11·51	± 5·75	± 8·14
		60°	1·7321	±18·45	±15·97	±18·45			60°	1·7321	± 8·82	± 7·64	± 8·82
		75°	3·7321	± 9·86	±18·39	±19·05			75°	3·7321	± 4·81	± 8·98	± 9·29
		90°	∞	..	±19·88	±19·88			90°	∞	..	±10·50	±10·50
C	Nitrided for 10 hr. at 485° C., tested "as nitrided"	0°	0	±38·19	..	±19·10	C	Nitrided for 10 hr. at 485° C., tested "as nitrided"	0°	0	±27·51	..	±13·75
		30°	0·5774	±33·89	± 9·78	±19·56			30°	0·5774	±23·60	± 6·81	±13·63
		45°	1·0000	±28·87	±14·43	±20·41			45°	1·0000	±21·14	±10·57	±14·94
		60°	1·7321	±22·23	±19·25	±22·23			60°	1·7321	±15·92	±13·79	±15·92
		90°	∞	..	±23·81	±23·81			90°	∞	..	±19·79	±19·79
D	Nitrided for 22 hr. at 485° C., tested "as nitrided"	0°	0	±38·43	..	±19·21	D	Nitrided for 22 hr. at 485° C., tested "as nitrided"	0°	0	±27·43	..	±13·72
		15°	0·2679	±36·29	± 4·86	±18·79			15°	0·2679	±25·77	± 3·45	±13·34
		20° 36′	0·3759	±35·57	± 6·68	±19·00			20° 36′	0·3759	±25·23	± 4·74	±13·47
		30°	0·5774	±33·68	± 9·72	±19·44			30°	0·5774	±24·01	± 6·93	±13·86
		45°	1·0000	±27·80	±13·90	±19·65			45°	1·0000	±20·78	±10·39	±14·70
		60°	1·7321	±20·90	±18·10	±20·90			60°	1·7321	±16·03	±13·89	±16·03
		75°	3·7321	±11·26	±20·99	±21·75			75°	3·7321	± 9·18	±17·13	±17·73
		90°	∞	..	±22·72	±22·72			90°	∞	..	±19·45	±19·45
F	Nitrided for 72 hr. at 485° C., tested "as nitrided"	0°	0	±40·70	..	±20·35	G	Nitrided for 72 hr. at 485° C., tested "as nitrided"	0°	0	±27·43	..	±13·72
		15°	0·2679	±38·91	± 5·21	±20·14			15°	0·2679	±25·29	± 3·39	±13·09
		20° 36′	0·3759	±38·33	± 7·20	±20·47			20° 36′	0·3759	±24·74	± 4·65	±13·21
		30°	0·5774	±36·32	±10·49	±20·97			30°	0·5774	±22·90	± 6·61	±13·22
		45°	1·0000	±30·17	±15·09	±21·33			45°	1·0000	±19·79	± 9·89	±14·00
		60°	1·7321	±23·01	±19·91	±23·01			60°	1·7321	±15·80	±13·68	±15·80
		75°	3·7321	±12·05	±22·49	±23·27			75°	3·7321	± 9·12	±17·01	±17·62
		90°	∞	..	±23·75	±23·75			90°	∞	..	±18·68	±18·68
E	Nitrided for 22 hr. at 485° C.; 0·004 in. ground off diameter of stressed length; tested "as ground"	0°	0	±38·63	..	±19·31							
		45°	1·0000	±28·65	±14·32	±20·26							
		90°	∞	..	±23·46	±23·46							

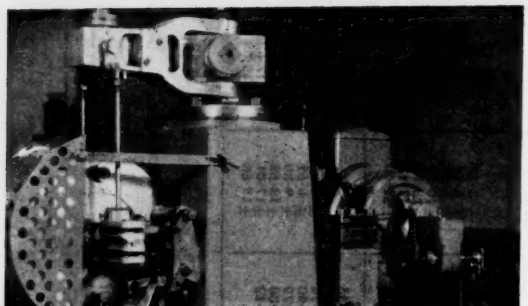

Fig. 14—Modified N.P.L. combined-stress fatigue machine

and heat-treated (½ hr. at 900° C., oil quenched ; ½ hr. at 595° C., oil quenched), and were polished longitudinally with "00" paper before testing. The tensile, izod, and fatigue properties were :

Limit of Proportionality ...	36·0 tons/sq. in.
0·1% Proof Stress	50·1 ,, ,,
0·2% Proof Stress	51·9 ,, ,,
Maximum Stress	61·3 ,, ,,
Elongation	21·5%
Reduction of Area	74·5%
Brinell (on surface of heat-treated bar)	302
Izod Impact Value	101, 103, 104 ft.lb.
Fatigue Limit (range of direct stress due to bending) ...	±33·75 tons/sq. in.

and the test results obtained on the Wöhler fatigue machine were as follows :

Reversed Bending Stress, tons/sq. in.	No. of Cycles
± 36·0	318,300 (broken)
± 34·5	1,905,100 (,,)
± 34·0	3,511,000 (,,)
± 33·75	25,426,400 (unbroken)
± 33·5	17,024,500 (,,)

A comparison of the fatigue results obtained on the modified combined-stress machine and the Wöhler machine is shown in the following :

	Modified N.P.L. Machine	Wöhler
Maximum Tensile Strength, tons/sq. in.	61·8	61·3
Fatigue Limit (reversed bending stresses), tons/sq. in.	± 32·97	± 33·75
Fatigue - Limit / Maximum-Tensile-Strength Factor ...	0·53	0·55

It was considered that the difference in the fatigue limits obtained on the two machines was only very slight (2·4%), and within the limits to be expected from two batches of similar material. Therefore, the tests on the modified combined-stress fatigue machine were continued, and during the progress of the tests the speed of the flywheel was frequently checked with a stroboscope, whilst periodic checks of the natural frequency were carried out with a Cambridge vibrograph, and any slight corrections to the speed of the flywheel, found to be necessary, were made by re-machining the motor or flywheel pulleys.

The fatigue limits obtained on the modified combined-stress machine, using type A specimens 0·600 in. in diameter at the section to be tested, in the un-nitrided condition, and in the as-nitrided condition (after nitriding for 10, 22, or 72 hr. at 485° C.), given as the range of max. shear stress (tons/sq. in.) induced in the specimen, were as follows :

Value of θ	(1)	Un-Nitrided	Nitrided 10 hr.	Nitrided 22 hr.	Nitrided 72 hr.
0°	0	±16·48	±19·10	±19·21	±20·35
15°	0·2679	±16·43	...	±18·79	±20·14
20° 36′	0·3759	±16·56	...	±19·00	±20·47
30°	0·5774	±17·21	±19·56	±19·44	±20·97
45°	1·0000	±18·06	±20·41	±19·65	±21·33
60°	1·7321	±18·45	±22·23	±20·90	±23·01
75°	3·7321	±19·05	...	±21·75	±23·27
90°	∞	±19·88	±23·81	±22·72	±23·75

(1)—Ratio of Applied Twisting Moment to Bending Moment—Tan θ

As previously stated, it has been noted by other investigators[2, 3, 10, and 11] that with reversed bending stresses the fatigue fractures of nitrided solid specimens, without any form of stress concentration, commenced in the vicinity of the junction between the case and the core. This present series of tests made on the modified combined-stress machine showed that, by superimposing reversed torsional stresses on a reversed bending stress, the fatigue fractures still commenced in the vicinity of the junction between the case and the core, for the specimens nitrided for 10, 22, or 72-hr. periods at 485° C. The approximate distance from the surface of the test-piece to where the fracture commenced was measured on a typical specimen for each fatigue limit determined, and a comparison of the results obtained, with the total depth of the nitrided case as determined by depth/hardness curves (*see* Fig. 1) was as follows :

Value of θ	(1)	(2) 10 hr.	(2) 22 hr.	(2) 72 hr.
0°	0	0·017	0·020	0·025
15°	0·2679	...	0·020	0·028
20° 36′	0·3759	...	0·020	0·026
30°	0·5774	0·015	0·020	0·026
45°	1·0000	0·017	0·020	0·026
60°	1·7321	0·017	0·020	0·024
75°	3·7321	...	0·018	0·028
90°	∞	...	0·025	0·026
Mean value		0·016	0·020	0·026
Total depth of nitrided case as determined by depth / hardness curves		0·014	0·016	0·023

(1)—Ratio of Applied Twisting Moment to Bending Moment—Tan θ
(2)—Approximate Distance (in.) from the Surface of the Test-Piece to where fracture commenced, after Nitriding at 485° C. for Different Times.

Note—Tested in the "As-Nitrided" Condition

The white areas which indicate that the fracture had commenced below the surface of the specimen, observed on the fractures of the nitrided solid fatigue test-pieces, were not perfectly circular, but they tended to become flattened when the white area reached the hardest portion of the nitrided case. It is probable that these white areas were formed by a relative slow initial propagation of the fatigue fracture, which was suddenly increased when the fracture reached the hardest portion of the nitrided case. Once the fatigue crack had penetrated to the surface of the fatigue specimen, it probably extended in a normal way, as for an un-nitrided test-piece.

The fatigue limits obtained with reversed bending stresses using solid test-pieces (0·600 in. dia.) before and after nitriding, showed that by increasing the

nitriding time and testing in the "as-nitrided" condition, the percentage increase in the fatigue limit due to nitriding was slightly increased. However, when torsional stresses were superimposed on the bending stresses the percentage increase in the fatigue limit due to nitriding was slightly higher for the 10-hr. period than for the 22-hr. period, as shown below :

Value of θ	(1)	(2) 10 hr.	(2) 22 hr.	(2) 72 hr.	(3) From 72 to 22 hr.	(3) From 72 to 10 hr.
0°	0	15·8	16·6	23·5	−5·6	−6·2
15°	0·2679	...	14·4	22·5	−6·7	...
20° 36′	0·3759	...	14·7	23·6	−7·2	...
30°	0·5774	13·7	12·9	21·8	−7·3	−6·7
45°	1·0000	13·0	8·8	18·1	−7·9	−4·3
60°	1·7321	20·5	13·3	24·7	−9·2	−3·4
75°	3·7321	...	14·2	22·2	−6·5	...
90°	∞	19·8	14·3	19·5	−4·3	+0·3
Mean value		16·6	13·6	22·0	−6·8	−4·1

(1)—Ratio of Applied Twisting Moment to Bending Moment—Tan θ
(2)—Increase in the Fatigue Limit, Due to Nitriding for Different Times at 485° C. (Tests Made in the "As-Nitrided" Condition), %
(3)—Difference in the Fatigue Limit, Due to Altering the Time of Nitriding at 485° C.; Tests Made in the "As-Nitrided" Condition, %

The slightly higher fatigue limits obtained by nitriding solid test-pieces of 0·600 in. dia. for 10 hr. at 485° C., instead of for 22 hr. at 485° C., could not be explained by the distance from the surface of the test-pieces where the fractures commenced, and it was thought that the slight variations obtained in the fatigue limits for the two nitriding treatments were due to experimental errors during the progress of the tests.

As previously stated, the approximate distance from the surface of the test-piece to where the fracture commenced, for the solid nitrided test-pieces, was measured on a typical specimen for each fatigue limit determined. From this dimension it was possible to calculate the range of maximum shear stress where the fracture commenced* (*see* Table V), and the following results were obtained :

Value of θ	(1)	(2) 10 hr.	(2) 22 hr.	(2) 72 hr.	(3)
0°	0	±18·00	±17·93	±18·65	±18·19
15°	0·2679	...	±17·54	±18·26	±17·90
20° 36′	0·3759	...	±17·73	±18·69	±18·21
30°	0·5774	±18·58	±18·13	±19·15	±18·62
45°	1·0000	±19·25	±18·34	±19·48	±19·02
60°	1·7321	±20·97	±19·50	±21·17	±20·55
75°	3·7321	...	±20·45	±21·10	±20·77
90°	∞	...	±20·83	±21·69	±21·26

(1)—Ratio of Applied Twisting Moment to Bending Moment—Tan θ
(2)—Fatigue Limit of Test-Pieces Nitrided for Different Times at 485° C. and Tested "As-Nitrided", tons/sq. in.
(3)—Mean Value of Fatigue Limit, tons/sq. in.

Value of θ	(1)	(2)	(3)	(4)	(5)
0°	0	±16·48	±18·19	+2·5	10·4
15°	0·2679	±16·43	±17·90	±2·0	9·0
20° 36′	0·3759	±16·56	±18·21	±2·6	10·0
30°	0·5774	±17·21	±18·62	+2·8	8·2
45°	1·0000	±18·06	±19·02	−3·6	5·3
60°	1·7321	±18·45	±20·55	−5·1	11·4
75°	3·7321	±19·05	±20·77	±1·5	9·0
90°	∞	±19·88	±21·26	±2·0	6·9

(1)—Ratio of Applied Twisting Moment to Bending Moment—Tan θ
(2)—Fatigue Limit of Un-Nitrided Test-Pieces, tons/sq. in.
(3)—Mean Value of Fatigue Limit, at the Position where Fracture Commenced, of Specimens Nitrided for 10, 22, or 72 hr. at 485° C., tons/sq. in.
(4)—Maximum Variation from the Mean Value, %
(5)—Increase of the Mean Value for the Approximate Range of Maximum Shear Stress at the Position where Fracture Commenced, for the Nitrided Test-Pieces, over that obtained for the Un-Nitrided Test-Pieces, %

With the exception of the tests carried out at 45° and 60°, the values for maximum shear stress at the position where the fracture commenced were very consistent for all three nitriding times. The average increase of the mean value for the approximate range of maximum shear stress at this position, over the fatigue limit obtained for the un-nitrided test-pieces, was 8·8%. It is probable that some of this increase was due to the nitrides penetrating beyond the end of the nitrided case, shown by the depth hardness curves, and to slightly increasing the fatigue properties of the material in the vicinity of the junction between the case and the core. However, as the fractures commenced below the surface of the test-piece they were not initiated by any scratch or machine mark on the surface of the specimens, or by any corrosion which occurred during the progress of the tests. Therefore, it is considered that a fair proportion of the 8·8% increase was due to the fracture not being initiated by any surface irregularities, and it is possible that the values for the approximate range of maximum shear stress, at the position where the fracture commenced, were the fatigue limits for a chromium–molybdenum steel, heat-treated to a maximum tensile strength of 60·0 tons/sq. in., having a perfect surface, and tested in a vacuum. It has been shown by Bardgett[11] that with nitrided solid test-pieces the fatigue fractures can be initiated in the vicinity of the junction between the case and the core by inclusions. However, with this present series of tests, in view of the consistency in the distance from the outside of the test-piece to where the fracture commenced for the three nitriding periods, it was considered highly improbable that the results obtained were affected to any appreciable extent by inclusions.

It was shown in the fatigue tests carried out on the modified combined-stress machine, that by reducing the time of nitriding solid test-pieces of 0·600 in. dia. (at the section to be stressed) from 72 hr. to 22 hr. or 10 hr. at 485° C., and by testing in the "as-nitrided" condition, the mean values for the reduction in the fatigue limit for reversed bending stresses, reversed torsional stresses, or various combinations of reversed bending and torsional stresses, were 6·8% and 4·1%, respectively. The tests also showed that the fatigue fractures commenced in the vicinity of the junction between the case and the core for all three nitriding periods, and that the positions of the commencement of the fatigue fractures for the 10, 22, and 72-hr. nitriding treatments were approximately 0·016, 0·020, and 0·026 in., respectively, below the surface of the specimens. It is highly probable that for larger-diameter solid test-pieces the position of the commencement of the fatigue fractures would be the same distance below the surface of the specimens for each nitriding treatment. Therefore, although the fatigue limits of the 0·600-in. dia. solid specimens were reduced approximately 6·8 and 4·1% by a decrease in the nitriding time from 72 to 22 or 10 hr. at 485° C., the percentage reduction in the fatigue limit would be considerably

* Unless otherwise stated the "fatigue limit" referred to in tabulated data is the range of max. shear stress at the position where fracture commenced.

less for larger-diameter solid test-pieces. As the size effect of the larger specimens should be the same for the three nitriding periods, it appeared that the percentage reduction in the fatigue limit (due to reducing the time of nitriding solid test-pieces of 3·0 in. diameter from 72 to 22 or 10 hr. at 485° C., for reversed bending stresses, reversed torsional stresses, or various combinations of reversed bending and torsional stresses) could be calculated approximately as follows :

(*a*) By reducing the nitriding time from 72 to 22 hr. at 485° C. :

The percentage reduction in the fatigue limit

$$= \frac{S_1\left(\frac{3\cdot0}{3\cdot0-(2\times0\cdot026)}\right)-S_1\left(\frac{3\cdot0}{3\cdot0-(2\times0\cdot020)}\right)\times\frac{100}{1}}{S_1\left(\frac{3\cdot0}{3\cdot0-(2\times0\cdot026)}\right)}$$

$$= \frac{1\cdot018\,S_1-1\cdot014\,S_1}{1\cdot018\,S_1}\times\frac{100}{1}=0\cdot4\ \%$$

(*b*) By reducing the nitriding time from 72 to 10 hr. :

The percentage reduction in the fatigue limit

$$= \frac{S_1\left(\frac{3\cdot0}{3\cdot0-(2\times0\cdot026)}\right)-S_1\left(\frac{3\cdot0}{3\cdot0-(2\times0\cdot016)}\right)\times\frac{100}{1}}{S_1\left(\frac{3\cdot0}{3\cdot0-(2\times0\cdot026)}\right)}$$

$$= \frac{1\cdot018\,S_1-1\cdot011\,S_1}{1\cdot018\,S_1}\times\frac{100}{1}=0\cdot7\%$$

S_1 = stress at the position where fracture commenced (*see* Table VI)

It would, therefore, be expected from these fatigue tests on solid 0·600-in. dia. specimens, that by nitriding crankshafts or airscrew shafts for 22 or 10 hr. instead of for 72 hr., at 485° C., the fatigue properties would be practically unaltered for sections of the components approximately 3·0 in. in diameter having no form of stress concentration. This statement was confirmed by a series of fatigue tests which were carried out at the Institution of Automobile Engineers on solid test-pieces, of 1·8 in. dia. at the stressed section, made from a chromium–molybdenum steel heat-treated to a maximum tensile strength of 60·0 tons/sq. in. and nitrided for 22 or 60 hr. at 485° C. It was stated by the above laboratory, on completion of these fatigue tests, that no appreciable difference in the limiting fatigue strength could be found between specimens nitrided for 60 or 22 hr. at 485° C.

EFFECT OF NITRIDING FOR 22 HR., AND THEN GRINDING, ON THE FATIGUE PROPERTIES OF SOLID TEST-PIECES

The section to be stressed of the test-pieces for this series of tests, was machined to 0·604 in. dia., and after nitriding for 22 hr. at 485° C. it was reduced to 0·600 in. dia. by grinding with a wheel having a 2·0-in. radius. No special precautions were taken during this final grinding operation, and the fatigue tests were carried out with the specimens in the "as-ground" condition.

It appeared, from the results obtained, that no detrimental effect to the fatigue properties was obtained by grinding 0·004 in. off the diameter of the stressed section of the nitrided solid fatigue specimens. Therefore, provided no cracks are produced on nitrided engine components made from a chromium–molybdenum steel, heat-treated to a maximum tensile strength of 60·0 tons/sq. in. and nitrided for 22 hr. at 485° C., by the final grinding operation to decrease the diameter by 0·004 in., the fatigue properties of the components would appear to be satisfactory.

The fractures of all the solid fatigue specimens, ground after nitriding, commenced in the vicinity of the junction between the case and the core, as for the nitrided solid fatigue specimens tested in the "as-nitrided" condition, whilst the angle of fracture to the longitudinal axis of the test-piece did not appear to be affected by the grinding operation.

The grinding operation carried out on the solid fatigue test-pieces after nitriding for 22 hr. at 485° C. reduced the thickness of the nitrided case by 0·002 in. and increased the surface hardness of the specimens from 770 to 925 V.P.N. (*see* Fig. 1). It has been previously shown with the solid fatigue test-pieces, tested in the "as-nitrided" condition, that by altering the nitriding treatment from 22 to 10 hr. at 485° C. the depth of the nitrided case was reduced 0·002 in. and the surface hardness was increased from 770 to 975 V.P.N. Therefore, by nitriding for 22 hr. at 485° C. and then grinding 0·004 in. off the diameter of the stressed section of the fatigue specimens, the surface hardness and depth of nitrided case of the finished machined test-pieces were approximately the same as those obtained by nitriding test-pieces for 10 hr. at 485° C. and tested in the "as-nitrided" condition, as shown by the following data :

Value of θ	(1)	(2)	(3)	(4)
0°	0	±19·21	±19·31	±19·10
45°	1·0000	±19·65	±20·26	±20·41
90°	∞	±22·72	±23·46	±23·81

Surface Hardness of Test-Pieces, V.P.N.	770	925	975
Depth of Nitrided Case, Measured by Fracture Test, in.	0·006	0·004	0·004
Total Depth of Nitrided Case Obtained from Depth/Hardness Curves	0·016	0·014	0·014
Approx. Distance from the Surface of the Test-Piece where the Fracture Commenced, in.	0·020	0·015	0·016

(1)—Ratio of Applied Twisting Moment to Bending Moment—Tan θ
(2)—Fatigue Limits of Test-Pieces Nitrided 22 hr. at 485° C. and Tested "As-Nitrided", tons/sq. in.
(3)—Fatigue Limits of Test-Pieces Nitrided 22 hr. at 485° C. and Tested after Grinding 0·004 in. off diameter, tons/sq. in.
(4)—Fatigue Limits of Test-Pieces Nitrided 10 hr. at 485° C. and Tested "As-Nitrided", tons/sq. in.

Value of θ	(1)	(2)	(3)	(4)
0°	0	−0·6	+0·5	−1·1
45°	1·0000	+3·9	+3·1	+0·7
90°	∞	+4·8	+3·3	+1·5

(1)—Ratio of Applied Twisting Moment to Bending Moment—Tan θ
(2)—Difference in Fatigue Limit Due to Altering the Time of Nitriding from 22 to 10 hr. at 485° C., Test made "As-Nitrided", %
3)—Difference in Fatigue Limit Due to Grinding 0·004 in. off the Test-pieces Nitrided for 22 hr. at 485° C., %
(4)—Difference between Fatigue Limits Obtained after Nitriding for 22 hr. at 485° C. and Grinding 0·004 in. off Diameter, and those Obtained after Nitriding for 10 hr. at 485° C. and Testing "As Nitrided", %

Table V

TESTS ON THE COMBINED-STRESS FATIGUE MACHINE ON SOLID CR–MO STEEL TEST-PIECES 0·600 IN. DIA. (TYPE A, *SEE* FIG. 3), AFTER NITRIDING FOR 10, 22, OR 72 HR. AT 485° C.

With the solid fatigue specimens tested in the nitrided condition, white areas (indicating that the fracture had commenced below the surface of the specimens) were clearly visible on the majority of the specimens, and the approximate stress at the position where the fracture commenced for test series C, D, E, and F is shown below

Value of θ	Test Series C (Nitrided for 10 hr. at 485° C. and Tested "As Nitrided")			Test Series D (Nitrided for 22 hr. at 485° C. and Tested "As Nitrided")			Test Series E (Nitrided for 22 hr. at 485° C. and then 0·004 in. Ground off Diameter of Stressed Section before Testing)			Test Series F (Nitrided for 72 hr. at 485° C. and Tested "As Nitrided")		
	Fatigue Limit (Range of Max. Shear Stress Induced in Specimen), tons/sq. in.	Approximate Distance from Outside of Test-piece where Fracture Commenced, in.	Approximate Range of Max. Shear Stress at the Position where Fracture Commenced, tons/sq. in.	Fatigue Limit (Range of Max. Shear Stress Induced in Specimen), tons/sq. in.	Approximate Distance from Outside of Test-piece where Fracture Commenced, in.	Approximate Range of Max. Shear Stress at the Position where Fracture Commenced, tons/sq. in.	Fatigue Limit (Range of Max. Shear Stress Induced in Specimen), tons/sq. in.	Approximate Distance from Outside of Test-piece where Fracture Commenced, in.	Approximate Range of Max. Shear Stress at the Position where Fracture Commenced, tons/sq. in.	Fatigue Limit (Range of Max. Shear Stress Induced in Specimen), tons/sq. in.	Approximate Distance from Outside of Test-piece where Fracture Commenced, in.	Approximate Range of Max. Shear Stress at the Position where Fracture Commenced, tons/sq. in.
0°	±19·10	0·017	±18·00	±19·21	0·020	±17·93	±19·31	0·015	±18·34	±20·35	0·025	±18·65
15°	...	...	...	±18·79	0·020	±17·54	...	...	...	±20·14	0·028	±18·26
20° 36′	...	...	...	±19·00	0·020	±17·73	...	...	...	±20·47	0·026	±18·69
30°	±19·56	0·015	±18·58	±19·44	0·020	±18·13	...	...	...	±20·97	0·026	±19·15
45°	±20·41	0·017	±19·25	±19·45	0·020	±18·34	±20·26	0·015	±19·25	±21·33	0·026	±19·48
60°	±22·23	0·017	±20·97	±20·90	0·020	±19·50	...	...	...	±23·01	0·024	±21·17
75°	...	...	...	±21·75	0·018	±20·45	...	...	...	±23·27	0·028	±21·10
90°	...	...	...	±22·72	0·025	±20·83	...	...	...	±23·75	0·026	±21·69

Notes. (1) With the test series C and E no distinct white areas were obtained on the fractures for reversed torsional stresses ($\theta = 90°$), and therefore the approximate range of maximum shear stress at the position where the fracture commenced could not be calculated for these tests

(2) The approximate range of maximum shear stress at the position where the fracture commenced was calculated by the following formula:

$$S_1 = S \times \frac{\left(\frac{D}{2} - d\right)}{\frac{D}{2}} = S \times \frac{D - 2d}{D}.$$

Therefore $S = S_1\left(1 - \frac{2d}{D}\right)$

Also $S = S_1\left(\frac{D}{D - 2d}\right)$

The fatigue limits obtained by the two methods of preparing the fatigue specimens were also approximately the same (maximum difference, 1·5%) for the stress conditions 1, 2, and 3.

It has been previously stated that the higher fatigue limits obtained by nitriding solid fatigue test-pieces for 10 instead of for 22 hr. at 485° C. (and testing in the "as-nitrided" condition) under stress conditions 2 or 3, were probably due to slight experimental errors during the progress of the tests. However, in view of the test results obtained on the solid fatigue test-pieces which were nitrided for 22 hr. at 485° C. and then ground to reduce the diameter of the stressed section by 0·004 in., it appeared probable that the higher surface hardness obtained with the 10-hr. nitriding treatment than with the 22-hr. nitriding treatment may have contributed to the slightly higher fatigue limits. As the fracture of all the solid nitrided fatigue test-pieces commenced in the vicinity of the junction between the case and the core, the slightly higher fatigue limits obtained after grinding, or by nitriding for 10 hr. instead of 22 hr. at 485° C., cannot have been caused directly by the higher surface hardness, but possibly by the higher surface hardness altering the distribution of the compressive and tensile stresses through the specimens.

As previously stated, the fracture of all the solid fatigue specimens tested after nitriding for 22 hr. at 485° C. and then grinding 0·004 in. off the diameter of the stressed section, commenced in the vicinity of the junction between the case and the core, as for the solid fatigue specimens tested in the "as-nitrided" condition. By measuring the distance from the outside of the test-piece to the point where the fracture commenced, it was possible to calculate the range of maximum shear stress at this position, as shown in Table V, and the results obtained, together with those obtained on the type A test-pieces nitrided for 10, 22, or 72 hr. at 485° C. and tested in the "as-nitrided" condition, are shown in Table VI. The approximate range of maximum shear stress at the position where the fracture commenced, was about the same for the solid specimens tested "as-nitrided" and for the solid specimens tested

after nitriding and grinding, as shown in the following :

Value of θ	(1)	(2)	(3)	(4)
0°	0	±18·19	±18·34	+0·8
45°	1·0000	±19·02	±19·25	+1·2

(1)—Ratio of Applied Twisting Moment to Bending Moment—Tan θ
(2)—Mean Value of Fatigue Limit of Specimens Nitrided 10, 22, or 72 hr. at 485° C. and Tested "As-Nitrided," tons/sq. in.
(3)—Fatigue Limit for Test-pieces Nitrided for 22 hr. at 485° C., and with 0·004 in. Ground off Diameter, tons/sq. in.
(4)—Difference in the Mean Value of Fatigue Limit Obtained "As-Nitrided" and the Value Obtained on the Nitrided Specimens Tested after Grinding 0·004 in. off Diameter, %

Note—As stated in Table V, no distinct white area was obtained on the fractures of the nitrided specimens tested after grinding, with reversed torsional stresses ($\theta = 90°$), and, therefore, the approximate range of maximum shear stress at the position where the fracture commenced, could not be calculated for these tests.

EFFECT OF NITRIDING AND TESTING IN THE "AS NITRIDED" CONDITION, ON THE FATIGUE PROPERTIES OF HOLLOW-WITH-OIL-HOLE TEST-PIECES

The test-pieces used for this series of tests were of 0·600 in. outside diameter and 0·232 in. inside diameter, with a 0·040-in. dia. oil hole, as shown in Fig. 3, (type B) and a summary of the fatigue results is given below :

Value of θ	(1)	(2)	(3) 10 hr.	(3) 22 hr.	(3) 72 hr.
0°	0	± 7·23	±13·75	±13·72	±13·72
15°	0·2679	± 7·37	...	±13·34	±13·09
20° 36′	0·3759	± 7·50	...	±13·47	±13·21
30°	0·5774	± 7·87	±13·63	±13·86	±13·22
45°	1·0000	± 8·14	±14·94	±14·70	±14·00
60°	1·7321	± 8·82	±15·92	±16·03	±15·80
75°	3·7321	± 9·29	...	±17·73	±17·62
90°	∞	±10·50	±19·79	±19·45	±18·68

(1)—Ratio of Applied Twisting Moment to Bending Moment—Tan θ
(2)—Fatigue Limit of Un-Nitrided Type B Test-Pieces, tons/sq. in.
(3)—Fatigue Limit of Type B Test-Pieces Nitrided for Different Times at 485° C. and Tested "As-Nitrided," tons/sq. in.

Value of θ	(1)	(2) 10 hr.	(2) 22 hr.	(3) 72 hr.
0°	0	90·2	89·8	89·8
15°	0·2679	...	81·0	77·6
20° 36′	0·3759	...	79·6	76·1
30°	0·5774	73·2	76·1	68·0
45°	1·0000	83·5	80·6	72·0
60°	1·7321	80·5	81·7	79·1
75°	3·7321	...	90·9	89·7
90°	∞	88·5	85·2	77·9
Mean value		83·2	83·1	78·8

(1)—Ratio of Applied Twisting Moment to Bending Moment—Tan θ
(2)—Increase in Fatigue Limit Due to Nitriding for Different Times at 485° C. and Testing "As-Nitrided," %

Value of θ	(1)	(2) 72 to 22 hr.	(2) 72 to 10 hr.
0°	0	Nil	+0·2
15°	0·2679	+1·9	...
20° 36′	0·3759	+2·0	...
30°	0·5774	+4·9	+3·1
45°	1·0000	+5·0	+6·7
60°	1·7321	+1·5	+0·8
75°	3·7321	+0·6	...
90°	∞	+4·1	+5·9
Mean value		+2·5	+3·3

(1)—Ratio of Applied Twisting Moment to Bending Moment—Tan θ
(2)—Difference in Fatigue Limit Due to Changing the Time of Nitriding at 485° C. Tested in the "As-Nitrided" Condition, %

The fatigue fracture of all the type B test-pieces in the un-nitrided or nitrided conditions, commenced at the surface of the oil hole, but owing to the small relative diameter of the test-pieces it was not possible to say whether the fracture commenced at the top or slightly down the hole (*see* Fig. 9).

The mean values for the percentage increase in the fatigue limit for the stress conditions 1, 2, or 3, were 83·2, 83·1, and 78·8, for the 10, 22, or 72 hr. nitriding periods, respectively. Therefore, it appeared that by altering the nitriding treatment for crankshafts and airscrew shafts from 72 to 10 hr. at 485° C., the fatigue limits of the components for the sections at the oil hole would be slightly increased. As the fatigue fractures of the nitrided type B specimens commenced on the surface of the nitrided case, the fatigue properties obtained after nitriding for 10 hr., slightly higher than after nitriding for 72 hr. at 485° C., appeared to be due to the higher surface hardness obtained after the 10-hr. nitriding treatment, or to a higher compressive stress on the surface after this treatment than after the 72-hr. nitriding, or to a combination of the two.

COMPARISON OF THE FATIGUE LIMITS OBTAINED WITH REVERSED BENDING STRESSES AND REVERSED TORSIONAL STRESSES, USING TYPES A AND B TEST-PIECES BEFORE AND AFTER NITRIDING

A summary of the factors for the fatigue limit obtained with reversed torsional stresses, divided by the fatigue limit obtained with reversed bending stresses, is given in the following :

Condition	Solid Test-Pieces (0·600 in. dia.)	Hollow Test-Pieces with an Oil Hole (0·600 in. outside dia.)
Un-nitrided	0·603	0·726
Nitrided for 10 hr. at 485° C. and tested "as nitrided"	0·623	0·719
Nitrided for 22 hr. at 485° C. and tested "as nitrided"	0·591	0·709
Nitrided for 22 hr. at 485° C. and reduced 0·004 in. in dia. by grinding, tested "as ground"	0·607	...
Nitrided for 72 hr. at 485° C. and tested "as nitrided"	0·584	0·681
Mean value	0·601	0·709
Maximum variation from mean value	+3·7%	−3·9%

The factors obtained for the five series of tests on the solid specimens were very consistent, the mean value being 0·601, with a maximum variation from the mean value of + 3·7%. A similar consistency was also obtained for the four series of type B specimens, but the factors were considerably higher for this type of specimen than for the type A specimens (mean values 0·709 and 0·601, respectively), and for both the type A and the type B specimens the factors were not affected by nitriding for 10, 22, or 72 hr. at 485° C.

GENERAL REMARKS

The transfer of the commencement of the fatigue fracture from the surface to the vicinity of the junction between the case and the core, due to nitriding solid fatigue specimens, minimizes the possibility of scratches and machining marks initiating fatigue failure. It is not definitely known what causes the commencement of the fatigue fracture to be transferred from the surface to below the surface by nitriding solid fatigue specimens, but it may be due to one or a combination of the following three reasons :

(*a*) Compressive stresses in the nitrided case
(*b*) The fatigue properties of the nitrided case being considerably higher than those of the core
(*c*) The modulus of elasticity of the case being considerably lower than that of the core

It is very doubtful whether nitriding will appreciably alter the modulus of elasticity of the material, and it has already been stated by Mailänder,[8] that the modulus of elasticity of nitrided steel is practically the same as that of un-nitrided steel.

A number of investigators[8, 9, and 11] have already shown that nitriding produces a compressive stress in the nitrided case, and this compressive stress will be balanced by a tensile stress in the core, and it is highly probable that these stresses will be decreased as the nitriding time is decreased.

The compressive stress in the nitrided case is beneficial, from a fatigue point of view, for reversed bending or reversed torsional stresses, but the tensile stress in the core may be detrimental for reversed bending or reversed torsional stresses on specimens or components of small cross-sectional area,[12] and for push-pull loading on specimens or components of small or large cross-sectional area. Therefore it appeared that the best nitriding treatment for solid specimens was the one which produced sufficient compressive stress in the nitrided case and sufficient depth of nitrided case, to transfer the commencement of the fatigue fracture from the surface to the vicinity of the junction between the case and the core, with a minimum tensile stress in the core. As the fractures of type B specimens commenced on the nitrided surface and not, as for type A specimens, below it, it appeared that the best nitriding treatment for type B was that which produced the maximum surface hardness. From an examination of the test results obtained in this present investigation, it appeared that the 10-hr. nitriding treatment at 485° C. was more suitable for crankshafts and airscrew shafts (which have cross-sections corresponding to both the type A and the type B test-pieces) than the 22- or 72-hr. nitriding treatments at 485° C.

However, for engine components the question of wear resistance has also to be considered. For crankshafts and airscrew shafts a nitrided case 0·004 in. deep as obtained by a 10-hr. nitriding treatment at 485° C. appeared to be quite sufficient. After this nitriding treatment the total depth of the nitrided case, as shown by a depth/hardness curve (*see* Fig. 1), was approximately 0·014 in., and at a depth of 0·004 in. the hardness was in the region of 700 V.P.N. Therefore, after nitriding a crankshaft, made from a chromium–molybdenum steel, for 10 hr. at 485° C. the journals could be reduced 0·008 in. in diameter without decreasing the surface hardness below 700 V.P.N. However, as shown in the following data and by the depth/hardness curves on Fig. 1, by reducing the time of nitriding from 72 to 10 hr. at 485° C. the maximum hardness of the case was obtained nearer the surface of the specimen, and the surface hardness and maximum case hardness were increased.

Time of Nitriding at 485° C.	Surface Hardness after Nitriding, V.P.N.	Maximum Case Hardness after Nitriding, V.P.N.	Distance Below the Surface at which the Maximum Case Hardness was Obtained
10 hr.	976	1050	0·001 in.
22 hr.	770	945	0·0007 in.
72 hr.	730	970	0·0025 in.

Note—Only the results obtained on the specimens nitrided in the laboratory furnace are given above, as all these specimens were from the same batch of material and nitrided under identical conditions.

Therefore, although it has been necessary in the past to grind up to 0·005 in. off the diameter of engine components after nitriding for 72 hr. at 485° C., in order to obtain the maximum hardness of the nitrided case on the surface of the finished component, and to correct for any distortion and growth which occurred

Table VI

TESTS ON THE COMBINED-STRESS FATIGUE MACHINE ON SOLID CR–MO STEEL TEST-PIECES 0·600 IN. DIA. (TYPE A, *SEE* FIG. 3), BEFORE AND AFTER NITRIDING FOR 10, 22, OR 72 HR. AT 485° C.

Value of θ	Un-Nitrided Test-Pieces	Nitrided Test-Pieces						Increase of the Mean Value for the Approximate Range of Maximum Shear Stress at Position where Fracture Commenced for Test Series C, D, E, and F, over the Fatigue Limit obtained for the Un-Nitrided Test-Pieces, %
	Fatigue Limit (Range of Max. Shear Stress Induced in Specimen), tons/sq. in.	Fatigue Limit (Approximate Range of Maximum Shear Stress at the Position where the Fracture Commenced), tons/sq. in.						
	Test Series A	Test Series C, Nitrided for 10 hr. at 485° C. and Tested "As Nitrided"	Test Series D, Nitrided for 22 hr. at 485° C. and Tested "As Nitrided"	Test Series E, Nitrided for 22 hr. at 485° C. and then dia. of Stressed Section reduced 0·004 in. by Grinding, Tested "As Ground"	Test Series F, Nitrided for 72 hr. at 485° C. and Tested "As Nitrided"	Mean Value for Test Series C, D, E, and F	Maximum Variation from Mean Value for Test Series C, D, E, and F, %	
0°	±16·48	±18·00	±17·93	±18·34	±18·65	±18·23	+2·3	10·6
15°	±16·43	...	±17·54	...	±18·26	±17·90	±2·0	9·0
20° 36′	±16·56	...	±17·73	...	±18·69	±18·21	±2·6	10·0
30°	±17·21	±18·58	±18·13	...	±19·15	±18·62	+2·8	8·2
45°	±18·06	±19·25	±18·34	±19·25	±19·48	±19·06	−3·9	5·6
60°	±18·45	±20·97	±19·50	...	±21·17	±20·55	−5·1	11·4
75°	±19·05	...	±20·45	...	±21·10	±20·77	±1·6	9·0
90°	±19·88	...	±20·83	...	±21·69	±21·26	±2·0	6·9

during the nitriding operation, after nitriding for 10 hr. at 485° C. this grinding operation might be replaced by a honing or lapping operation. This seemed to be a possibility, as the surface hardness obtained after nitriding for 10 hr. at 485° C. appeared to be quite adequate (976 V.P.N.) and as the compressive stresses in the nitrided case and the tensile stresses in the core will most likely be reduced when nitriding for 10 hr. instead of for 72 hr. at 485° C. it is highly probable that the distortion which occurs during the nitriding operation will also be reduced.

The grinding of nitrided cases, which have fairly large compressive stresses and a Vickers diamond hardness number of 750–950, requires a considerable amount of care, as grinding cracks are very easily produced. Therefore, if this grinding operation can be omitted by reducing the time of nitriding from 72 to 10 hr. at 485° C. the manufacture of engine crankshafts and airscrew shafts will have been simplified.

Part II—TESTS ON NICKEL–CHROMIUM–MOLYBDENUM AND CHROMIUM–MOLYBDENUM–VANADIUM STEELS

SYNOPSIS

The tests showed that by machining the solid, hollow, or hollow-with-oil-hole fatigue test-pieces from a heat-treated 3½-in. dia. bar of Cr–Mo–V steel (90 tons/sq. in. maximum tensile strength) instead of from a heat-treated 1-in. dia. bar of Ni–Cr–Mo steel (60·0 tons/sq. in. maximum tensile strength), the fatigue limits were increased approximately 31% for reversed bending, reversed torsional, or various combinations of reversed bending and torsional stresses. It appeared from fatigue tests which have already been completed in our laboratory on steels heat-treated to give maximum tensile strength values of between 60·0 and 113·0 tons/sq. in., that for solid test-pieces, with the standard longitudinal polish, tested under reversed bending stresses, the fatigue limit obtained in the longitudinal direction was only slightly increased by increasing the maximum tensile strength from 90·0 to 113·0 tons/sq. in.

The fatigue limits of the hollow specimens machined from both the Ni–Cr–Mo and Cr–Mo–V steels were approximately 1% lower than the fatigue limits obtained for solid specimens from the same steel, whilst the 0·020-in. dia. oil hole reduced the fatigue limit of both steels by approximately 50% for the three stress conditions. Therefore, as the percentage decrease in the fatigue limit due to the 0·020-in. dia. oil hole was approximately the same for both steels, it appeared that by increasing the maximum tensile strength from approximately 60·0 to 90·0 tons/sq. in., the stress concentration produced by the oil hole had not been increased.

DETAILS OF MATERIALS USED

THE Ni–Cr–Mo steel was supplied in 1-in. dia. rolled bars to specification D.T.D. 228, whilst the Cr–Mo–V steel was supplied in 3½-in. dia. rolled bars to specification D.T.D. 551. The chemical composition, heat-treatment, tensile and izod properties of both materials are given in Table VII. The heat treatment of the Cr–Mo–V steel was carried out before sectioning, to ensure that the mechanical properties obtained in this present investigation could be reproduced in an engine crankshaft or in an airscrew shaft.

FATIGUE TESTS

The tests were carried out at approximately 2100 cycles/min. on the combined-stress fatigue machine shown in Fig. 15, which was designed at The National Physical Laboratory,[1] and the following fatigue limits were determined :

Material	Test Series	Type of Test-Piece (*see* Fig. 3)	Value of θ*
Nickel–Chromium–Molybdenum Steel	A	Solid (type F)	0°, 15°, 20°36′,
	B	Hollow (type G)	30°, 45°, 60°,
	C	Hollow, with oil hole (type H)	75°, and 90°
Chromium–Molybdenum–Vanadium Steel†	D	Solid (type F)	0°, 15°, 20°36′,
	E	Hollow (type G)	30°, 45°, 60°,
	F	Hollow, with oil hole (type H)	75°, and 90°

* When $\theta = 0°$ reversed bending stresses are obtained, whilst when $\theta = 90°$ reversed torsional stresses are obtained, and for the remaining angles the stresses are partly reversed torsional and partly reversed bending.

† After heat treatment the bars for the fatigue tests were sectioned as shown in Fig. 17.

On completion of the turning operations, the solid and the hollow test-pieces were polished longitudinally on the stressed section with "00" polishing paper, whilst the hollow test-pieces with an oil hole were polished longitudinally on the stressed section with "00" paper before drilling the oil holes.

The test results obtained are shown in Table VIII, whilst the fatigue limits are shown in Table X and plotted in Fig. 16.

The angle the fracture made with the longitudinal axis of the test-piece was 90° for the specimens tested with reversed bending stresses, and the angle decreased as torsional stresses were superimposed on the bending stresses. It was found that the angles of fracture were very similar for the solid, the hollow, and the hollow test-pieces with an oil hole, and the specimens shown in Figs. 12 and 13 were typical for the solid or hollow test-pieces, and for the hollow test-pieces with an oil hole.

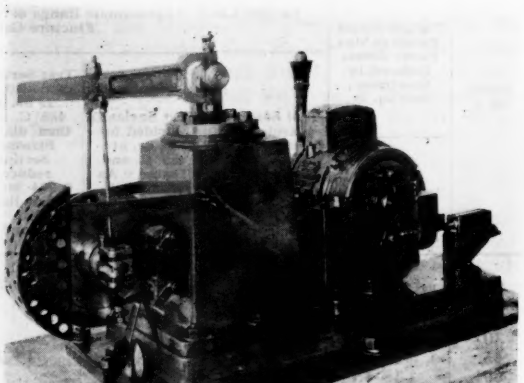

Fig. 15—N.P.L. combined-stress fatigue machine

Table VII

CHEMICAL COMPOSITION, HEAT-TREATMENT, AND MECHANICAL PROPERTIES OF THE NI–CR–MO AND CR–MO–V STEELS

Chemical Composition

Material	Test Series	Diameter of Bar, in.	Analysis C, %	Si, %	Mn %	S, %	P, %	Ni, %	Cr, %	Mo, %	V, %
Nickel–Chromium–Molybdenum Steel	A, B, and C	1	0·35	0·33	0·62	0·021	0·014	0·94	0·94	0·90	...
Chromium–Molybdenum–Vanadium Steel	D, E, and F	3½	0·39	0·28	0·58	0·017	0·006	0·17	3·07	0·98	0·20

Heat-Treatment

Material	Test Series	Diameter of Bar, in.	Types of Test Carried Out	Heat-Treatment Carried Out after Cutting Bars to Test Length and before Sectioning or Machining
Nickel–Chromium–Molybdenum Steel	A, B, and C	1	Tensile, izod, and fatigue (types F, G, and H test-pieces)	870° C. (½ hr. soak), oil quenched 690° C. (½ hr. soak), oil quenched
Chromium–Molybdenum–Vanadium Steel	D, E, and F	3½	Tensile, izod, and fatigue (types F, G, and H test-pieces)	900° C. (1 hr. soak), oil quenched 600° C. (1 hr. soak), oil quenched

Note—The microstructure obtained for the Ni–Cr–Mo and Cr–Mo–V steels after oil hardening and tempering revealed moderately coarse and moderately fine sorbitic structures, respectively, as shown in Figs. 6 and 7

Tensile and Izod Properties

Material	Test Series	Diameter of Bar, in.	Tensile Properties: Limit of Proportionality, tons/sq. in.	0·1% P.S., tons/sq. in.	Max. Stress, tons/sq. in.	Elongation, %	R. of A., %	Brinell (on Surface of Heat-Treated Bar	Izod Impact Value, ft.lb.	Remarks
Nickel–Chromium–Molybdenum Steel	A, B, and C	1	43·0	53·6	60·2	25·3	71·6	286	92, 98	
Chromium–Molybdenum–Vanadium Steel	D, E, and F	3½	55·5	74·9	90·5	12·5	54·0	418	16,17,20	(1)
			55·0	73·2	88·0	14·5	59·0	418	...	(2)

Note. (1) Tensile and izod test-pieces TO and IO (*see* Fig. 17)
(2) Tensile test-piece TI (*see* Fig. 17)
The tensile tests were carried out using the test-piece type K, Fig. 3 (gauge length polished longitudinally with "00" polishing paper), and a Huggenberger extensometer (1 div. = 0·000334 in.)
The izod tests were carried out using the test-piece type E, Fig. 3

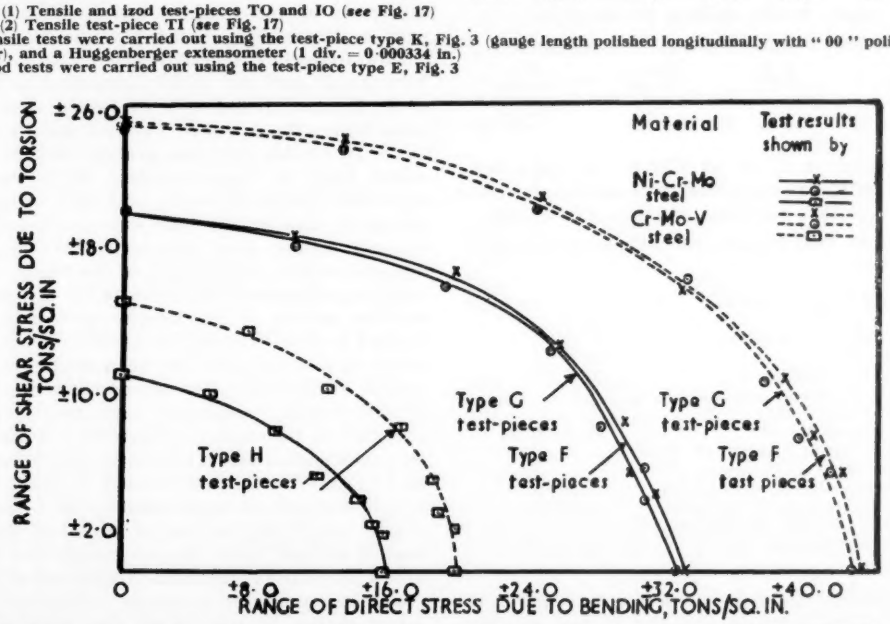

Fig. 16—Fatigue test results obtained on Ni–Cr–Mo and Cr–Mo–V steels (max. tensile strength 60·2 and 90·5 tons/sq. in. respectively)

DISCUSSION OF RESULTS

COMPARISON OF THE FATIGUE LIMITS OBTAINED ON THE COMBINED-STRESS AND THE WÖHLER FATIGUE MACHINES

The first series of tests for this present investigation was carried out on the combined-stress fatigue machine, with reversed bending stresses, using solid (type F) and hollow (type G) specimens and hollow specimens with an oil hole (type H), machined from the Ni–Cr–Mo steel, whilst fatigue tests were also carried out with reversed bending stresses on a Wöhler machine, using a similar steel and the uniform

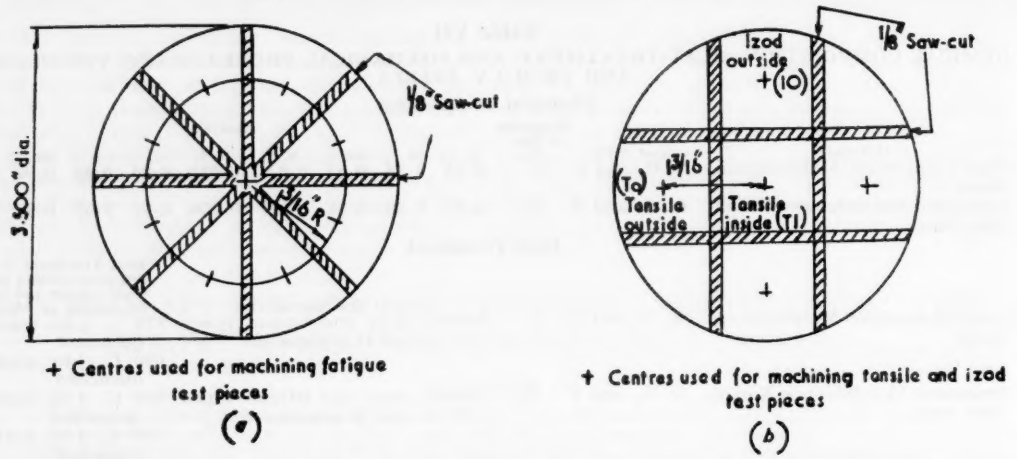

Fig. 17—Method of sectioning 3·5 in. dia. bar of Cr–Mo–V steel; (*a*) fatigue tests, (*b*) tensile and izod tests

bending type of specimens (types C, I, and J) shown in Fig. 3.

The test-pieces for this series of Wöhler fatigue tests were machined from heat-treated 1-in. dia. rolled bar, and the test results obtained are shown in Table IX. On completion of the turning operations, the solid and the hollow test-pieces were polished longitudinally on the stressed section with "00" polishing paper, before drilling the oil hole.

The chemical composition of the steel was :

C, %	Si, %	Mn, %	S, %
0·28	0·21	0·56	0·021
P, %	**Ni, %**	**Cr, %**	**Mo, %**
0·012	0·75	0·98	1·04

Heat-treatment (½ hr. at 870° C., oil quenched ; ½ hr. at 690° C., oil quenched) was carried out after the 1-in. dia. bars had been cut into test lengths.

The tensile, izod impact, and fatigue properties of the steel were :

Limit of Proportionality	37·0 tons/sq. in.
0·1% Proof Stress	54·4 " "
Maximum Tensile Stress	61·2 " "
Elongation	25·0%
Reduction of Area	68·6%
Brinell Hardness (on surface of heat-treated bar)	286
Izod Impact Value	71–84 ft.lb.
Fatigue Limit (Range of Direct Stress Due to Bending)	
Solid (type C) test-pieces	± 32·75
Hollow (type I) test-pieces	± 32·50
Hollow, with oil hole (type J) test-pieces	± 14·75

A comparison of the fatigue limits obtained on the combined-stress machine and the Wöhler machine, is shown in the following :

	Maximum Tensile Strength of Material, tons/sq. in.		Fatigue Limit (Reversed Bending), tons/sq. in.		Factor : Fatigue Limit / Maximum Tensile Strength	
Type of Test-Piece	Combined-Stress Machine	Wöhler Machine	Combined-Stress Machine	Wöhler Machine	Combined-Stress Machine	Wöhler Machine
Solid	60·2	61·2	±33·00	±32·75	0·55	0·54
Hollow	60·2	61·2	±32·20	±32·50	0·53	0·53
Hollow, with oil hole	60·2	61·2	±15·21	±14·75	0·25	0·24

It was considered that the difference in the fatigue limits and the fatigue-limit/maximum-tensile-strength factors obtained on the two machines was only very slight and within the limits to be expected from two batches of similar material. Therefore the tests on the combined-stress fatigue machine were continued using test-pieces (types F, G, and H) machined from the Ni–Cr–Mo steel. During the progress of the tests the speed of the flywheel was frequently checked with a stroboscope, whilst periodic checks of the natural frequency were carried out with a Cambridge Vibrograph, and any slight corrections to the speed of the flywheel, found to be necessary, were made by remachining the motor or flywheel pulleys.

The Ni–Cr–Mo steel was heat-treated, in 1-in. dia. rolled bars, to approximately 60·0 tons/sq. in. maximum tensile strength, and then specimens for the tensile and fatigue tests were machined with the stressed section from the centre of the bar, the diameter of the gauge length of the tensile specimens being approximately the same as the diameter of the stressed section of the fatigue specimens. It was decided to heat-treat the Ni–Cr–Mo steel in 1-in. dia. rolled bars, as this steel has been used in the past for engine crankshafts and airscrew shafts, and the desired tensile properties have been consistently obtained on the engine components. However, when the investigation was extended to include fatigue tests on a Cr–Mo–V steel, heat-treated to give a maximum tensile strength of approximately 90·0 tons/sq. in., it was considered essential to heat-treat this steel in bars of at least 3½-in. dia., to ensure that the mechanical properties obtained in this present investigation could be reproduced in engine crankshafts and airscrew shafts, because when the investigation was commenced this steel had not been used for those

Table VIII (*a*)

TEST RESULTS OBTAINED ON THE COMBINED-STRESS FATIGUE MACHINE WITH SOLID (TYPE F) TEST-PIECES

Nickel–Chromium–Molybdenum Steel						Chromium–Molybdenum–Vanadium Steel					
Value of θ	Range of Direct Stress Due to Bending, tons/sq. in.	Range of Shear Stress Due to Torsion, tons/sq. in.	Range of Maximum Shear Stress Induced in Specimen, tons/sq. in.	No. of Cycles	Estimated Fatigue Limit in Terms of Maximum Shear Stress, tons/sq. in.	Value of θ	Range of Direct Stress Due to Bending, tons/sq. in.	Range of Shear Stress Due to Torsion, tons/sq. in.	Range of Maximum Shear Stress Induced in Specimen, tons/sq. in.	No. of Cycles	Estimated Fatigue Limit in Terms of Maximum Shear Stress, tons/sq. in.
0°	±37·00	. .	±18·50	137,767 (B)	±16·50	0°	±45·23	. .	±22·62	630,547 (B)	±21·63
	±36·00	. .	±18·00	149,354 (B)			±44·26	. .	±22·13	2,549,390 (B)	
	±35·00	. .	±17·50	302,806 (B)			±43·76	. .	±21·88	12,978,763 (B)	
	±34·00	. .	±17·00	231,308 (B)			±43·26	. .	±21·63	79,372,478 (UB)	
	±33·50	. .	±16·75	978,361 (B)			±42·90	. .	±21·45	63,294,360 (UB)	
	±33·00	. .	±16·50	10,086,417 (UB)							
15°	±33·30	±4·46	±17·23	298,143 (B)	±16·00	15°	±43·75	±5·86	±22·65	713,139 (B)	±21·63
	±32·40	±4·33	±16·77	544,005 (B)			±42·75	±5·72	±22·13	956,158 (B)	
	±31·40	±4·21	±16·26	1,022,022 (B)			±42·31	±5·67	±21·90	1,679,465 (B)	
	±30·90	±4·14	±16·00	10,032,159 (UB)			±41·79	±5·60	±21·63	6,414,265 (B)	
							±41·30	±5·53	±21·39	51,667,704 (UB)	
										32,372,646 (UB)	
20° 36′	±30·90	±5·80	±16·50	479,007 (B)	±15·76	20° 36′	±42·34	±7·95	±22·62	387,755 (B)	±21·38
	±30·50	±5·72	±16·29	1,284,841 (B)			±41·43	±7·78	±22·13	324,387 (B)	
	±30·00	±5·63	±16·03	4,644,248 (B)			±40·51	±7·61	±21·64	1,871,848 (B)	
	±29·50	±5·53	±15·76	31,352,183 (UB)			±40·02	±7·52	±21·38	21,163,915 (UB)	
							±39·60	±7·44	±21·16	48,902,296 (UB)	
30°	±30·30	±8·75	±17·49	549,374 (B)	±16·75	30°	±41·77	±12·05	±24·11	229,548 (B)	±22·13
	±29·50	±8·50	±17·03	2,002,927 (B)			±40·92	±11·81	±23·63	246,209 (B)	
	±29·00	±8·37	±16·75	10,041,628 (UB)			±40·07	±11·57	±23·14	438,022 (B)	
							±39·16	±11·31	±22·62	937,561 (B)	
							±38·78	±11·19	±22·39	3,983,070 (B)	
							±38·32	±11·06	±22·13	20,015,459 (UB)	
45°	±25·74	±13·76	±19·47	248,829 (B)	±18·00	45°	±36·23	±18·11	±25·62	874,620 (B)	±22·87
	±26·83	±13·42	±18·97	878,603 (B)			±35·53	±17·76	±25·12	1,729,763 (B)	
	±26·52	±13·25	±18·75	661,425 (B)			±35·53	±17·76	±25·12	432,693 (B)	
	±26·27	±13·08	±18·22	2,596,104 (B)			±35·10	±17·54	±24·82	803,693 (B)	
	±26·45	±12·72	±18·00	10,011,387 (UB)			±34·17	±17·08	±24·16	16,736,718 (B)	
							±34·17	±17·08	±24·16	14,399,630 (B)	
							±33·64	±16·81	±23·36	13,445,580 (B)	
							±32·73	±16·36	±23·34	23,482,756 (B)	
							±32·35	±16·17	±22·87	79,348,555 (UB)	
60°	±20·10	±17·40	±20·10	484,820 (B)	±19·30	60°	±25·83	±22·37	±25·83	537,848 (B)	±24·30
	±19·60	±17·00	±19·60	1,446,900 (B)			±25·34	±21·94	±25·34	778,073 (B)	
	±19·30	±16·70	±19·30	15,067,220 (UB)			±24·82	±21·49	±24·82	1,710,857 (B)	
	±19·10	±16·50	±19·10	11,982,880 (UB)			±24·57	±21·26	±24·57	16,168,665 (B)	
							±24·30	±21·03	±24·30	63,262,196 (UB)	
75°	±10·40	±19·40	±20·10	847,940 (B)	±19·30	75°	±14·16	±26·40	±27·35	825,208 (B)	±25·04
	±10·30	±19·20	±19·90	1,014,580 (B)			±13·74	±25·63	±26·54	3,304,392 (B)	
	±10·10	±18·90	±19·50	1,114,120 (B)			±13·36	±24·91	±25·81	3,305,914 (B)	
	±10·00	±18·70	±19·30	11,745,160 (UB)			±13·12	±24·46	±25·34	20,791,898 (B)	
							±12·96	±24·17	±25·04	51,123,736 (UB)	
90°	. .	. .	±21·00	996,677 (B)	±20·00	90°	. .	±26·56	±26·56	1,267,072 (B)	±25·28
	. .	±20·50	±20·50	3,611,824 (B)			. .	±26·30	±26·30	993,809 (B)	
	. .	±20·25	±20·25	12,963,497 (B)			. .	±25·79	±25·79	2,200,200 (B)	
	. .	±20·00	±20·00	43,131,659 (UB)			. .	±25·53	±25·53	37,416,624 (B)	
								±25·28	±25·28	55,542,756 (UB)	

(B) = Broken, (UB) = Unbroken

Table VIII (*b*)

TEST RESULTS OBTAINED ON THE COMBINED-STRESS FATIGUE MACHINE WITH HOLLOW (TYPE G) TEST-PIECES

Nickel–Chromium–Molybdenum Steel						Chromium–Molybdenum–Vanadium Steel					
Value of θ	Range of Direct Stress Due to Bending, tons/sq. in.	Range of Shear Stress Due to Torsion, tons/sq. in.	Range of Maximum Shear Stress Induced in Specimen, tons/sq. in.	No. of Cycles	Estimated Fatigue Limit in Terms of Maximum Shear Stress, tons/sq. in.	Value of θ	Range of Direct Stress Due to Bending, tons/sq. in.	Range of Shear Stress Due to Torsion, tons/sq. in.	Range of Maximum Shear Stress Induced in Specimen, tons/sq. in.	No. of Cycles	Estimated Fatigue Limit in Terms of Maximum Shear Stress, tons/sq. in.
0°	±34·70 ±33·70 ±32·70 ±32·20	.. ..	±17·35 ±16·85 ±16·35 ±16·10	336,576 (B) 320,044 (B) 509,527 (B) 11,584,623 (UB)	±16 10	0°	±45·80 ±44·86 ±43·79 ±43·27 ±42·75	.. ..	±22·90 ±22·43 ±21·89 ±21·63 ±21·37	166,744 (B) 409,944 (B) 3,541,296 (B) 2,518,488 (B) 58,058,984 (UB)	±21·37
15°	±32·60 ±31·60 ±31·10 ±30·60	± 4 37 ± 4·23 ± 4·16 ± 4·10	±16·87 ±16·36 ±16·10 ±15·84	279,350 (B) 262,111 (B) 338,978)B) 10,056,179 (UB)	±15·84	15°	±44·04 ±42·68 ±42·19 ±41·70 ±41·20	± 5·90 ± 5·72 ± 5·65 ± 5·59 ± 5·52	±22·80 ±22·10 ±21·84 ±21·58 ±21·33	133,134 (B) 395,929 (B) 435,927 (B) 1,270,000 (B) 32,760,784 (UB)	±21·33
20° 36′	±32·60 ±30·60 ±30·10	± 6·14 ± 5·74 ± 5·64	±17·40 ±16·35 ±16·08	529,900 (B) 1,482,460 (B) 11,894,680 (UB)	±16·08	20° 36′	±42·78 ±42·30 ±41·82 ±41·33 ±40·85 ±40·39 ±39·92 ±39·43	± 8·04 ± 7·95 ± 7·86 ± 7·77 ± 7·68 ± 7·59 ± 7·51 ± 7·41	±22·84 ±22·60 ±22·34 ±22·08 ±21·82 ±21·57 ±21·32 ±21·06	384,681 (B) 466,510 (B) 402,537 (B) 548,199 (B) 1,185,258)B) 982,512 (B) 7,959,225 (B) 150,098,514 (UB)	±21·06
30°	±29·20 ±28·70 ±28·20	± 8·40 ± 8·30 ± 8·20	±16·86 ±16·57 ±16·30	313,403 (B) 1,379,794 (B) 12,138,840 (UB)	±16·30	30°	±38·70 ±38·26 ±37·83 ±37·39	±11·18 ±11·05 ±10·92 ±10·79	±22·34 ±22·10 ±21·84 ±21·58	444,858 (B) 1,375,208 (B) 32,075,640 (B) 52,050,401 (UB)	±21·58
45°	±26·60 ±25·50 ±25·20	±13·30 ±12·80 ±12·60	±18·80 ±18·00 ±17·80	211,680 (B) 1,995,280 (B) 11,831,540 (UB)	±17·80	45°	±36·13 ±33·09 ±33·05 ±32·68	±18·06 ±16·54 ±16·52 ±16·34	±25·55 ±23·40 ±23·37 ±23·11	207,264 (B) 11,011,792 (B) 1,707,587 (B) 30,065,763 (UB)	±23·11
60°	±19·35 ±19·10 ±18·80	±16·76 ±16·50 ±16·30	±19·35 ±19·10 ±18·80	309,820 (B) 694,120 (B) 14,803,880 (UB)	±18·80	60°	±26·03 ±25·08 ±24·59 ±24·36 ±24·12	±22·54 ±21·71 ±21·29 ±21·09 ±20·88	±26·03 ±25·08 ±24·59 ±24·36 ±24·12	726,784 (B) 1,323,280 (B) 3,890,960 (B) 5,843,512 (B) 65,162,340 (UB)	±24·12
75°	±10·50 ±10·10 ±10·00 ± 9·90	±19·60 ±18·90 ±18·70 ±18·40	±20·30 ±19·50 ±19·30 ±19·10	522,480 (B) 1,078,700 (B) 1,013,460 (B) 14,914,060 (UB)	±19·10	75°	±13·59 ±13·34 ±13·10 ±12·97 ±12·85 ±12·73	±25·35 ±24·90 ±24·43 ±24·20 ±23·97 ±23·76	±26·25 ±25·78 ±25·29 ±25·05 ±24·82 ±24·60	187,816 (B) 305,448 (B) 1,208,244 (B) 1,035,192 (B) 764,144 (B) 44,599,508 (UB)	±24·60
90°	.. ..	±21·00 ±20·50 ±20·25 ±20·00	±21·00 ±20·50 ±20·25 ±20·00	1,218,848 (B) 1,465,400(B) 1,609,266(B) 16,431,019 (UB)	±20·00	90°	.. ..	±27·21 ±26·04 ±25·81 ±25·33 ±25·04	±27·21 ±26·04 ±25·81 ±25·33 ±25·04	187,928 (B) 1,336,587 (B) 709,809 (B) 6,271,116 (B) 57,854,513 (UB)	±25·04

(B) = Broken ; (UB) = Unbroken

Table VIII (*c*)

	..	±20·00	±20·00	16,431,019 (UB)			..	±25·04	±25·04	57,854,513 (UB)	

(B) = Broken ; (UB) = Unbroken

Table VIII (*c*)

TEST RESULTS OBTAINED ON THE COMBINED-STRESS FATIGUE MACHINE WITH HOLLOW, WITH OIL HOLE, (TYPE H) TEST-PIECES

Nickel–Chromium–Molybdenum Steel						Chromium–Molybdenum–Vanadium Steel					
Value of θ	Range of Direct Stress Due to Bending, tons/sq. in.	Range of Shear Stress Due to Torsion, tons/sq. in.	Range of Maximum Shear Stress Induced in Specimen, tons/sq. in.	No. of Cycles	Estimated Fatigue Limit in Terms of Maximum Shear Stress, tons/sq. in.	Value of θ	Range of Direct Stress Due to Bending, tons/sq. in.	Range of Shear Stress Due to Torsion, tons/sq. in.	Range of Maximum Shear Stress Induced in Specimen, tons/sq. in.	No. of Cycles	Estimated Fatigue Limit in Terms of Maximum Shear Stress, tons/sq. in.
0°	±16·71 ±15·71 ±15·21	.. .. ..	± 8·35 ± 7·85 ± 7·60	324,027 (B) 441,086 (B) 15,075,660 (UB)	± 7·60	0°	±21·93 ±20·49 ±19·97 ±19·48 ±19·00	.. ..	±10·97 ±10·25 ± 9·99 ± 9·74 ± 9·50	282,109 (B) 176,455 (B) 542,764 (B) 27,039,542 (UB) 72,998,295 (UB)	± 9·74
15°	±16·07 ±15·65 ±15·15	± 2·15 ± 2·10 ± 2·03	± 8·31 ± 8·10 ± 7·85	873,185 (B) 1,468,331 (B) 11,314,738 (UB)	± 7·85	15°	±20·24 ±20·24 ±19·80 ±19·29 ±19·29	± 2·71 ± 2·71 ± 2·65 ± 2·58 ± 2·58	±10·47 ±10·47 ±10·25 ± 9·99 ± 9·99	196,138 (B) 598,046 (B) 1,461,332 (B) 47,926,215 (UB) 36,123,733 (UB)	± 9·99
20° 36′	±16·79 ±15·59 ±15·17 ±14·70	± 3·16 ± 2·93 ± 2·85 ± 2·76	± 8·97 ± 8·33 ± 8·10 ± 7·85	557,902 (B) 2,653,700 (B) 2,593,678 (B) 14,757,716 (UB)	± 7·85	20° 36′	±21·07 ±20·08 ±19·65 ±19·15 ±18·67 ±18·67	± 3·96 ± 3·78 ± 3·70 ± 3·60 ± 3·51 ± 3·51	±11·26 ±10·73 ±10·50 ±10·23 ± 9·98 ± 9·98	469,056 (B) 1,283,342 (B) 1,566,870 (B) 2,254,862 (B) 38,722,626 (UB) 33,085,200 (UB)	± 9·98
30°	±14·87 ±14·41 ±13·95	± 4·29 ± 4·16 ± 4·03	± 8·58 ± 8·32 ± 8·06	896,737 (B) 1,800,450 (B) 14,747,343 (UB)	± 8·06	30°	±19·91 ±19·05 ±18·61 ±18·61 ±18·15 ±18·15	± 5·75 ± 5·50 ± 5·37 ± 5·37 ± 5·24 ± 5·24	±11·50 ±11·00 ±10·75 ±10·75 ±10·48 ±10·48	257,143 (B) 713,635 (B) 785,668 (B) 1,183,249 (B) 62,508,412 (UB) 37,962,265 (UB)	±10·48
45°	±12·84 ±12·53 ±12·11 ±11·77 ±11·43	± 6·45 ± 6·29 ± 6·09 ± 5·89 ± 5·69	± 9·08 ± 8·86 ± 8·56 ± 8·32 ± 8·08	517,242 (B) 742,671 (B) 676,010 (B) 1,552,842 (B) 11,857,703 (UB)	± 8·08	45°	±17·32 ±16·63 ±16·26	± 8·66 ± 8·32 ± 8·13	±12·25 ±11·76 ±11·50	661,983 (B) 1,345,464 (B) 32,394,598 (UB)	±11·50
60°	± 9·80 ± 9·54 ± 9·28 ± 9·06	± 8·49 ± 8·26 ± 8·04 ± 7·85	± 9·80 ± 9·54 ± 9·28 ± 9·06	750,554 (B) 2,159,831 (B) 2,713,584 (B) 23,236,059 (UB)	± 9·06	60°	±13·02 ±12·49 ±12·26 ±12·00	±11·27 ±10·81 ±10·60 ±10·39	±13·02 ±12·49 ±12·26 ±12·00	718,940 (B) 5,097,913 (B) 1,348,954 (B) 24,001,986 (UB)	±12·00
75°	± 5·84 ± 5·59 ± 5·45 ± 5·32	±10·90 ±10·43 ±10·17 ± 9·93	±11·28 ±10·80 ±10·53 ±10·27	781,395 (B) 1,970,498 (B) 2,626,732 (B) 11,764,904 (UB)	±10·27	75°	± 7·77 ± 7·37 ± 7·24 ± 7·10 ± 6·99	±14·49 ±13·76 ±13·51 ±13·25 ±13·04	±15·01 ±14·23 ±13·98 ±13·72 ±13·50	814,147 (B) 1,107,726 (B) 33,091,621 (UB) 23,735,769 (UB) 51,377,127 (UB)	±13·98
90°	.. ..	±12·76 ±12·25 ±11·75 ±11·25 ±11·00	±12·76 ±12·25 ±11·75 ±11·25 ±11·00	668,986 (B) 1,211,508 (B) 1,252,721 (B) 4,209,903 (B) 20,771,968 (UB)	±11·00	90°	.. ..	±16·47 ±15·99 ±15·50 ±15·25 ±15·01	±16·47 ±15·99 ±15·50 ±15·25 ±15·01	993,672 (B) 1,852,073 (B) 1,629,411 (B) 39,107,683 (UB) 35,539,088 (UB)	±15·25

(B) = Broken; (UB = Unbroken

components. In order to ensure that the tensile properties obtained for this steel (90·0 tons/sq. in. maximum tensile strength) were representative of the fatigue tests, the heat-treated 3½-in. dia. bars were sectioned as shown in Fig. 17, and the gauge-length diameter of the tensile specimen was approximately the same as the diameter of the stressed section of the fatigue specimens.

It was realized, when making a comparison of the fatigue results obtained on the Ni–Cr–Mo steel (60·0 tons/sq. in. maximum tensile strength) and Cr–Mo–V steel (90·0 tons/sq. in. maximum tensile strength), that it must not be overlooked that the bars used for machining the fatigue specimens were heat-treated in 1-in. and 3½-in. dia. sections respectively. However, as the tensile specimen for the Cr–Mo–V steel was machined from the same position of the 3½-in. dia. bar as the fatigue specimens, it appeared from fatigue results previously obtained in our laboratory on various steels, that the fatigue-limit/maximum-tensile-strength factor was not affected to any appreciable extent by heat-treating the bars in the 3½-in. dia. section, instead of in a 1-in. dia. section, as shown in the following :

Type of Steel	Tempering Temperature after Hardening, °C.	Size of Rolled Bar	Machining Carried out Prior to Heat-Treatment	Maximum Tensile Strength, tons/sq. in.	Fatigue Limit (Reversed Bending), tons/sq. in.	Factor : Fatigue Limit / Maximum Tensile Strength
Ni–Cr–Mo	650	5 × 5 in.	Bar sectioned to produce 1 in. square test length	60·0	±31·81*	0·53
Ni–Cr–Mo	690	1-in. dia.	Nil	60·2	±33·00†	0·55
Ni–Cr–Mo	690	1-in. dia.	Nil	61·2	±32·75‡	0·54
Cr–Mo	595	1-in. dia.	Nil	61·3	±33·75‡	0·55
Cr–Mo	580	1⅝-in. dia.	Nil	61·8	±32·97*	0·53
Ni–Cr–Mo	630	1⅝-in. dia.	Nil	62·2	±35·00‡	0·56
Ni–Cr–Mo	650	5 × 5 in.	Bar sectioned to produce 1-in. square test length	62·3	±34·83†	0·56
Ni–Cr–Mo	650	5 × 5 in.	Bar sectioned to produce 1-in. square test length	62·6	±32·50‡	0·52
Ni–Cr	620	1-in. dia.	Nil	63·3	±36·50†	0·58
Ni–Cr–Mo	575	1-in. dia.	Nil	71·5	±38·20†	0·53
Ni–Cr–Mo	600	1-in. dia.	Nil	70·2	±37·50‡	0·53
Ni–Cr–Mo	570	1-in. dia.	Nil	78·2	±41·90‡	0·54
Ni–Cr–Mo	575	5 × 5 in.	Bar sectioned to produce 1-in. square test length	79·0	±41·25‡	0·52
Ni–Cr–Mo	590	5 × 5 in.	Bar sectioned to produce 1-in. square test length	79·1	±42·00‡	0·53
Cr–Mo	550	3½-in. dia.	Nil	82·1	±41·75‡	0·51
Ni–Cr	200	1-in. dia.	Nil	90·0	±43·19†	0·48
Cr–Mo–V	600	3½-in. dia.	Nil	90·5	±43·26†	0·48
Ni–Cr–Mo	200	5 × 5 in.	Bars sectioned and test lengths rough-machined	113·0	±45·50‡	0·40

All the tests were carried out in the longitudinal direction
* Tests carried out on combined-stress fatigue machine using solid type of specimen 0·600 in. dia. at stressed section, type A, Fig. 3
† Tests carried out on combined-stress fatigue machine using solid type of specimen 0·300 in. dia. at stressed section, type F, Fig. 3
‡ Tests carried out on Wöhler fatigue machine using solid uniform-bending type of specimen 0·275 in. dia. at stressed section, type C., Fig. 3

The fatigue-limit/maximum-tensile-strength factor obtained for thirteen series of fatigue tests on solid specimens, tested with reversed bending stresses only, varied between 0·52 and 0·56, although the maximum tensile strength varied between 60·0 and 79·1 tons/sq. in. It therefore appeared from these tests that the fatigue limit increased in approximately the same proportion as the maximum tensile strength, for values of the latter property of between approximately 60·0 and 80·0 tons/sq. in. A factor of 0·58 was obtained for one series of tests on the combined-stress fatigue machine using solid specimens 0·300 in. in diameter (type F) with a maximum tensile strength of 63·3 tons/sq. in., but from an examination of the remaining results this factor appeared to be high and not typical for material of this tensile strength. When the maximum tensile strength was increased above 80·0 tons/sq. in., the factor for the fatigue limit (obtained using solid specimens with reversed bending stresses) divided by the maximum tensile strength, was decreased from approximately 0·52 for a steel with a maximum tensile strength of 80·0 tons/sq. in., to 0·48 and 0·40 for steels with maximum tensile strengths of 90·0 and 113·0 tons/sq. in. respectively. Therefore, for solid specimens with the standard longitudinal polish, tested under reversed bending stresses, it appeared that the fatigue limit was only slightly increased by increasing the maximum tensile strength from 90·0 to 113·0 tons/sq. in.

When a series of fatigue tests is carried out in our laboratory using 1-in. dia. rolled bar, the usual procedure is to heat-treat a number of tensile test lengths to various (Brinell) hardnesses, and then to carry out the tests after machining the gauge length of the tensile specimens to approximately the same diameter as the stressed section of the proposed fatigue tests, and from the same position of the bar. From these preliminary tensile tests a particular hardness on the outside surface of the bar is selected as giving the required maximum tensile strength, and then all the test lengths for the fatigue tests are heat-treated to this hardness. This occasionally necessitates the retempering of a number of bars, and the tempering treatment stated in the paper is the average temperature and minimum soaking time given to the test lengths. When the tests on the

Table IX

TESTS RESULTS OBTAINED ON THE WÖHLER FATIGUE MACHINE (NI-CR-MO STEEL)

Solid Test-Pieces Type C		Hollow Test-Pieces Type I		Hollow-with-oil-hole, Test-Pieces Type J	
Reversed Bending Stress, tons/sq. in.	No. of Cycles	Reversed Bending Stress, tons/sq. in.	No. of Cycles	Reversed Bending Stress, tons/sq. in.	No. of Cycles
±35·0	266,800 (B)	±33·75	324,900 (B)	±15·75	1,625,500 (B)
±34·0	369,700 (B)	±33·50	943,900 (B)	±15·50	2,215,700 (B)
±33·5	627,100 (B)	±33·00	833,400 (B)	±15·25	2,949,700 (B)
±33·0	788,900 (B)	±32·75	1,620,000 (B)	±15·00	3,013,400 (B)
±32·75	10,250,000 (UB)	±32·50	10,025,500 (UB)	±14·75	10,091,100 (UB)
±32·5	11,307,400 (UB)				

(B) = Broken ; (UB) = Unbroken

3½-in. dia. bars of Cr–Mo–V steel were commenced, the same procedure was followed as for the 1-in. dia. bars, but in addition, a further Brinell check was made on each test length after sectioning the bar. These extra hardness tests were carried out on the outside surface of the bar, and it was found necessary to allow a slight variation from the desired figure of 418, and the sectioned test lengths were accepted for machining with a Brinell hardness number of between 402 and 418 (*i.e.*, plus nil minus 4% on the desired Brinell hardness numeral).

COMPARISON OF THE FATIGUE LIMITS OBTAINED ON THE COMBINED-STRESS MACHINE BETWEEN NI-CR-MO STEEL AND CR-MO-V STEEL

The fatigue limits obtained on the above two steels are given in Table X and the percentage increase in the fatigue limit obtained by using a Cr–Mo–V steel heat-treated to a maximum tensile strength of approximately 90·0 tons/sq. in., instead of a Ni–Cr–Mo steel heat-treated to a maximum tensile strength of approximately 60·0 tons/sq. in., is shown in the following :

Value of θ	(1)	(2) Type F Test-Pieces (0·300 in. Dia.)	(2) Type G Test-Pieces (0·300 in. O.D.)	(2) Type H Test-Pieces (0·300 in. O.D.)
0°	0	31·1	32·7	28·2
15°	0·2679	35·2	34·7	27·3
20° 36′	0·3759	35·7	31·0	27·1
30°	0·5774	32·1	32·4	30·0
45°	1·0000	27·1	30·0	42·3
60°	1·7321	25·9	28·3	32·4
75°	3·7321	29·7	28·8	36·1
90°	∞	26·4	25·2	38·6
Mean value		30·4	30·4	32·7

(1)—Rate of Applied Twisting Moment to Bending Moment—Tan θ
(2)—Increase in the Fatigue Limit Obtained with Cr–Mo–V Steel instead of Ni–Cr–Mo Steel, %

With the types F and G test-pieces it appeared that the percentage increase in the fatigue limit obtained with the Cr–Mo–V steel instead of the Ni–Cr–Mo steel was slightly less for reversed torsional stresses than for reversed bending stresses, but with type H test-pieces the reverse appeared to be the case. The smallest increment of stress which can be obtained on the combined-stress fatigue machine used for this present investigation is 0·5 tons/sq. in. when $\theta = 0°$ (*i.e.*, reversed bending stresses), and therefore it is possible to obtain a variation of 0·5 tons/sq. in. in the fatigue limit obtained from two batches of similar material. The fatigue limits obtained for the type F Ni–Cr–Mo and Cr–Mo–V steel specimens with reversed bending stresses were ± 33·0 and ± 43·26 tons/sq. in. respectively, and therefore the increase in the fatigue limit obtained with Cr–Mo–V steel instead of Ni–Cr–Mo steel was 31·1%. However, if the fatigue limits had been ± 32·5 and ± 43·76 tons/sq. in. respectively, the increase in the fatigue limit would have been 34·6%. Therefore, as only slight differences in the fatigue limits resulted in quite appreciable variations in the value for the percentage increase in the fatigue limit obtained with Cr–Mo–V, instead of Ni–Cr–Mo, steel, it appeared that a more reliable figure for the increase due to changing the material would be the mean values for the eight tests on each type of specimen. These mean values were 30·4, 30·4, and 32·7 for the types F, G, and H test-pieces respectively, and it was considered that the agreement between the values obtained for the different types of specimens was very close. As previously stated, the maximum tensile strengths of the Ni–Cr–Mo and Cr–Mo–V steels were approximately 60·0 and 90·0 tons/sq. in., the test pieces being machined from heat-treated 1-in. and 3½-in. dia. bars respectively, and therefore it appeared from these present tests that by increasing the maximum tensile strength approximately 50%, the fatigue limit of types F, G, and H test-pieces was increased by approximately 31%.

With both the Ni–Cr–Mo and Cr–Mo–V steels, the percentage change in the fatigue limit obtained with a hollow test-piece instead of a solid test-piece was very slight, but in thirteen cases out of sixteen the fatigue limit obtained for the solid test-pieces was slightly higher than the value obtained for the hollow test-pieces, as shown in the following :

Value of θ	Ratio of Applied Twisting Moment to Bending Moment—Tan θ	Change in the Fatigue Limit Obtained with a Hollow Test-Piece Instead of a Solid Test-Piece, % Ni–Cr–Mo Steel	Cr–Mo–V Steel
0°	0	−2·4	−1·2
15°	0·2679	−1·0	−1·4
20° 36′	0·3759	+2·0	−1·5
30°	0·5774	−2·7	−2·4
45°	1·0000	−1·1	+1·0
60°	1·7321	−2·6	−0·7
75°	3·7321	−1·0	−1·8
90°	∞	Nil	−1·0
Mean value		−1·1	−1·1

Table X

FATIGUE LIMITS OBTAINED ON THE COMBINED-STRESS FATIGUE MACHINE (NI–CR–MO AND CR–MO–V STEELS)

Nickel–Chromium–Molybdenum Steel (Maximum Tensile Strength 60·2 tons/sq. in.)						Chromium–Molybdenum–Vanadium Steel (Maximum Tensile Strength 90·5 tons/sq. in.)					
Test Series	Type of Test-Piece	Value of θ	Ratio of Applied Twisting Moment to Bending Moment—Tan θ	Fatigue Limits, tons/sq. in.			Test Series	Type of Test-Piece	Value of θ	Ratio of Applied Twisting Moment to Bending Moment—Tan θ	Fatigue Limits, tons/sq. in.		
				Range of Direct Stress Due to Bending	Range of Shear Stress Due to Torsion	Range of Maximum Shear Stress Induced in Specimen					Range of Direct Stress Due to Bending	Range of Shear Stress Due to Torsion	Range of Maximum Shear Stress Induced in Specimen
A	Solid, 0·300 in. dia. (type F, *see* Fig. 3)	0°	0	±33·00	±4·14	±16·50	D	Solid, 0·300 in. dia. (type F, *see* Fig. 3)	0°	0	±43·26	±5·60	±21·63
		15°	0·2679	±30·90	±4·83	±16·00			15°	0·2679	±41·79	±7·52	±21·63
		20° 36′	0·3759	±29·50	±5·53	±15·76			20° 36′	0·3759	±40·02	±11·06	±21·38
		30°	0·5774	±29·00	±8·37	±15·75			30°	0·5774	±38·32	±16·17	±22·13
		45°	1·0000	±25·45	±12·72	±18·00			45°	1·0000	±32·35	±21·03	±22·67
		60°	1·7321	±19·30	±16·70	±19·30			60°	1·7321	±24·36	±24·17	±24·30
		75°	3·7321	±10·00	±18·70	±19·30			75°	3·7321	±12·96	±21·03	±25·04
		90°	∞	⋮	±20·00	±20·00			90°	∞	⋮	±25·28	±25·28
B	Hollow, 0·300 in. O.D. (type G, *see* Fig. 3)	0°	0	±32·20	⋮	±16·10	E	Hollow, 0·300 in. O.D. (type G, *see* Fig. 3)	0°	0	±42·75	⋮	±21·37
		15°	0·2679	±30·60	±4·10	±15·84			15°	0·2679	±41·20	±5·52	±21·33
		20° 36′	0·3759	±30·10	±5·64	±16·08			20° 36′	0·3759	±39·43	±7·41	±21·06
		30°	0·5774	±28·20	±8·20	±16·30			30°	0·5774	±37·39	±10·79	±21·58
		45°	1·0000	±25·20	±12·60	±17·80			45°	1·0000	±32·68	±16·34	±23·11
		60°	1·7321	±18·80	±16·30	±18·80			60°	1·7321	±24·12	±20·88	±24·12
		75°	3·7321	±9·90	±18·40	±19·10			75°	3·7321	±12·73	±23·76	±24·60
		90°	∞	⋮	±20·00	±20·00			90°	∞	⋮	±25·04	±25·04
C	Hollow-with-oil-hole, 0·300 in. O.D. (type H, *see* Fig. 3)	0°	0	±15·21	⋮	⋮	F	Hollow-with-oil-hole, 0·300 in. O.D. (type H, *see* Fig. 3	0°	0	±19·48	⋮	⋮
		15°	0·2679	±15·15	±2·03	±7·60			15°	0·2679	±19·29	±2·58	±9·74
		20° 36′	0·3759	±14·70	±2·76	±7·85			20° 36′	0·3759	±18·67	±3·51	±9·99
		30°	0·5774	±13·95	±4·03	±8·06			30°	0·5774	±18·15	±5·24	±9·98
		45°	1·0000	±11·43	±5·69	±8·08			45°	1·0000	±16·26	±8·13	±10·48
		60°	1·7321	±9·06	±7·85	±9·06			60°	1·7321	±12·00	±10·39	±11·50
		75°	3·7321	±5·32	±9·93	±10·27			75°	3·7321	±7·24	±13·51	±12·00
		90°	∞	⋮	±11·00	±11·00			90°	∞	⋮	±15·25	±13·98
													±15·25

The mean value for the percentage change in the fatigue limit obtained with a hollow test-piece was the same for the eight series of tests on the Ni–Cr–Mo steel, and for the eight series of tests on the Cr–Mo–V steel.

It will be noted from the test results shown in Table VIII that only three test-pieces were used to determine the fatigue limit of the hollow Ni–Cr–Mo steel specimens with $\theta = 20° 36'$, 30°, 45°, and 60°, and four test-pieces for each of the remaining four fatigue limits of this series. This was because of the excellent agreement obtained between the fatigue limits of the solid and hollow test-pieces, and from the results of tests on the two steels, given above, it does not appear that the values for the fatigue limits were affected to any great extent by the small number of test-pieces used to determine each fatigue limit.

The fatigue limits obtained on the Ni–Cr–Mo and Cr–Mo–V steels using types G and H test-pieces, are shown in Table X, and the percentage reductions in the fatigue limit due to the 0·020-in. dia. oil hole are shown in the following :

Value of θ	Ratio of Applied Twisting Moment to Bending Moment—Tan θ	Decrease in the Fatigue Limit Due to the Oil Hole, % Ni–Cr–Mo Steel	Cr–Mo–V Steel
0°	0	52·8	54·4
15°	0·2679	50·4	53·2
20° 36′	0·3759	51·2	52·6
30°	0·5774	50·6	51·4
45°	1·0000	54·6	50·2
60°	1·7321	51·8	50·2
75°	3·7321	46·2	43·2
90°	∞	45·0	39·1
Mean value		50·3	49·3

It appeared that with both the Ni–Cr–Mo and Cr–Mo–V steels the percentage decrease in the fatigue limit due to the oil hole was slightly less for reversed torsional stresses than for reversed bending stresses. As previously explained it is possible, with the combined-stress fatigue machine used for these present tests, to obtain a variation of 0·5 tons/sq. in. in the fatigue limit from two batches of similar material, and therefore for a comparison of the percentage decrease in the fatigue limit due to the oil hole for the two steels, it was considered that the mean values obtained for the eight series of tests on each material would be more reliable. These values were 50·3 and 49·3 for the Ni–Cr–Mo and Cr–Mo–V steels respectively, and therefore it appeared that by increasing the maximum tensile strength from approximately 60·0 to 90·0 tons/sq. in., the stress concentration caused by an oil hole had not been increased.

COMPARISON OF THE FATIGUE LIMITS OBTAINED WITH REVERSED BENDING STRESSES AND REVERSED TORSIONAL STRESSES USING TEST-PIECES MACHINED FROM NI–CR–MO AND CR–MO–V STEELS

The fatigue limits obtained on the above two steels are given in Table X, and a summary of the factors for the fatigue limit obtained with reversed torsional stresses, divided by the fatigue limit obtained with reversed bending stresses, is given in the following :

Type of Test-Piece	Factor: Fatigue Limit (Reversed Torsion) / Fatigue Limit (Reversed Bending) Ni–Cr–Mo Steel	Cr–Mo–V Steel
Type F (0·300 in. dia.)	0·606	0·584
Type G (0·300 in. O.D.)	0·621	0·586
Type H (0·300 in. O.D.)	0·723	0·783

The factors for the four series of tests on the solid or hollow specimens were very consistent, the mean value being 0·599, with a maximum variation from the mean value of + 3·7%. However, the agreement between the factors obtained for the two series of tests on the type H specimens was not so good as for the type F or G specimens, and the factors were considerably higher for the type H specimens than for the types F or G specimens (mean values 0·599 and 0·753 respectively).

Acknowledgments

This investigation was carried out as part of a research programme on the fatigue properties of crankshaft and airscrew shaft materials, and the author wishes to thank Dr. H. Sutton, of the Ministry of Supply, and the Directors of the Bristol Aeroplane Co., Ltd., for permission to publish this paper. The author also wishes to thank Messrs. F. Nourse and E. R. Gadd for their interest throughout the work, and Messrs. J. G. Owen, J. E. Taylor, and A. H. Coles for assistance in carrying out the investigatory work.

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A Note on the Determination of Moisture in Producer Gas

By J. Pearson, Ph.D., M.Sc., F.R.I.C., and
R. Toye, B.Sc., A.M.I.E.E., A.Inst.P.

SYNOPSIS

Control of the moisture content of producer gas may be essential for the correct working of gas producers. Very little information on methods of estimating this moisture has been published in English technical literature, and it is therefore hoped that this note, which describes several suitable methods, including one developed by the authors, will be of value to fuel technologists and to others engaged in the operation of open-hearth furnaces.

SEVERAL investigators[1–3] of open-hearth-furnace operation have described the undesired effect on the flame of an excessive proportion of water vapour in the gas. Others[4, 5] have suggested that certain unsatisfactory operating conditions in the gas producer, not revealed by the usual methods of control, can be deduced from a knowledge of the moisture content of the gas. The absence of information in English technical literature on methods of moisture determination suitable for application at the producer bench, has hampered investigation of these statements. It is therefore hoped that this description of some techniques which have been used successfully will contribute towards the more efficient working of open-hearth furnaces.

It is well known that flame luminosity is due to the white heat of finely divided solid particles in the flame. Consequently any process tending to decrease the number of solid particles will reduce the heat transfer by luminous radiation. The solid particles in a producer-gas flame consist of finely divided "skeletons" derived from the chemical breakdown of the tar during preheating in the regenerators. Wesemann[1] states that this reaction reaches its optimum at a temperature in the region of 900–1000° C. If moisture is present in the gas at this stage, a water-gas reaction

$$C + H_2O \rightarrow CO + H_2 \text{ or } CO_2 + H_2$$

is likely to take place, consuming the carbon as it is formed, *i.e.*, before it can cause the desired brightening of the flame. Fortunately the water-gas reaction does not reach its optimum until a temperature of 1200–1250° C. is reached,[2] so that if the amount of moisture present is only moderate, there is very little harm done at temperatures in the region of 1000° C. However, when the moisture becomes excessive, the water-gas reaction proceeds at an appreciable rate even at this lower temperature; any attempt to inhibit the reaction by lowering the preheat temperature defeats its own object because at a lower temperature the breakdown of the tar is incomplete. The moisture content of the gas should thus be kept to a minimum. Wesemann[1] says, "a moisture content in excess of 100 g./cu. m. greatly decreases the luminosity of the producer-gas flame."

The moisture in the gas has several possible sources, two of which can be traced to the producer: (1) The use of coal of high moisture content, and (2) incomplete decomposition of steam and moisture blown into the producer.

The moisture content of the coal is usually known from laboratory analysis. Of the second source Rosin[5] has stated, "The steam addition may be too high; the mixture between air and steam imperfect; the steam may be too wet; the reactivity of the coke residue towards steam decomposition may be too low; the contact between steam and coke surface may be low owing to channelling." He adds, "It is impossible to state the reason and remedy the cause unless measurements are available of the exact steam/air ratio and the moisture in the gas." The view that frequent humidity determination helps in controlling the producer is also held by de Graaf.[4]

An additional routine measurement at the producer bench, before being recommended, must first be justified. It is the opinion of one of the authors (R. T.) that moisture determinations at the producer can reveal little about the condition of the fuel bed (except, of course, excessive moisture in the green coal) that cannot be deduced from the CO_2 figures, together with blast saturation and gas temperatures. It will be seen that all the factors in Rosin's statement above will also give rise to a high CO_2 value, and when steps have been taken to reduce the CO_2 content of the gas to a minimum, it will be found that the moisture content also has fallen.

Nevertheless, the authors consider it desirable that there should be available at steelplants using producer gas, a method for determining its moisture content. If, for example, accurate gas calorific values are

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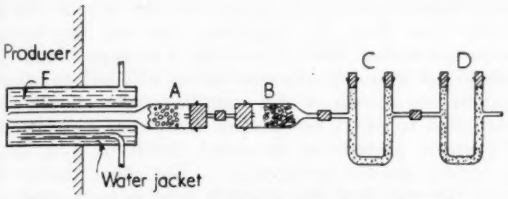

Fig. 1—Jenkner's water-estimation apparatus

required, then a knowledge of the moisture content is essential; values as high as 20% by volume have been encountered, meaning that the dry-gas analysis figures usually quoted should be multiplied by $\frac{5}{6}$ to give the true values. Again, possible moisture pick-up between producer and regenerator can be detected, or the correlation of variations in flame luminosity and melting time with variations in the moisture content of the gas can be investigated.

The methods described in the following pages are grouped as chemical or physical. In the chemical methods two conditions are essential for an absolute method for estimating water vapour: (i) The method employed for the actual estimation of water should be specific for water, and (ii) provision should be made to measure *all* moisture condensed from the gas sample.

CHEMICAL METHODS

Jenkner's Method

In Jenkner's method[6] a measured volume of gas is drawn off from the producer through two previously weighed calcium chloride tubes *C* and *D* (Fig. 1). The tapered end of tube *A* which is inserted into the neck of the producer is cooled by the water jacket *F*. The wider end of tube *A*, and the tube *B*, are packed with 5-mm. lengths of small-diameter glass tubing and cotton wool to ensure that all tar and dust are removed from the gas before it passes through the calcium chloride tubes. By this means condition (i) is satisfied, *i.e.*, when *C* and *D* are weighed after the gas has passed, any increase in weight will be due to water only and not to water plus tar and dust. After *A* has been withdrawn from the producer a stream of warm dry air is passed through the apparatus to carry over into the calcium chloride any moisture condensed in *A* and *B*, thus satisfying condition (ii).

Belcher and Allen's Method*

Owing to the duration for which the stream of dry air has to be passed, and the extreme length of the apparatus, the previous method is too cumbersome for routine works use. The apparatus to be carried to the producer should be as simple as possible. Belcher and Allen employed a method which eliminates the need for tar and dust filters, the gas passing through pyridine, where water, dust, and tar are deposited. The water condensed in the pyridine is then allowed to react with calcium hydride to produce a volume of hydrogen proportional to the moisture collected. To collect moisture condensed out before the absorption bottle, scavenging plugs of dry material are pushed through the sampling tube down into the pyridine.

* No description of this method has been published.

In this method there are two operations where large errors might easily arise: the first is the "mopping-up" operation. When it is realized that the total moisture content of 500 ml. of gas is about 60 mg., one or two drops of water only, it will be seen that any loss here can give rise to a very serious error in the final result. Secondly, the calcium hydride has to be highly pure and in powder form if the reaction with water is to be completed within a reasonable time; the addition of powdered CaH_2 to the pyridine without contact with moist air is not an easy operation.

The Authors' Method

The method developed by the authors employs the well-known Fischer reagent. This mixture of methyl alcohol, pyridine, iodine, and sulphur dioxide,* reacts with practically nothing but water[7] so that other constituents of the producer gas will cause no difficulty. The method has the advantage that standardization is carried out against weighed amounts of water under the same conditions as when a gas sample is being examined. Although direct titration is not the most accurate method of using the Fischer reagent or of noting end-points, such a procedure has been employed, and the authors' experience has indicated that the slight loss of accuracy is more than compensated by the simplification of apparatus and procedure.

In the following pages are described: (*a*) a collecting technique which overcomes condensation troubles, thus complying with condition (ii) above, and (*b*) a volumetric method for the estimation of moisture which is specific for water, and thus complies with condition (i).

Apparatus and Collecting Technique—A pyrex tube *AB* (Fig. 2), fitted with a ground-glass cone at *C*, and insulated along the greater part of its length with asbestos cord, has the end *A* inserted into the

* *Preparation*—Dissolve 85 g. of resublimed iodine in 270 ml. pyridine and add 667 ml. of methyl alcohol. Cool the vessel in a slurry of ice and add carefully 64 g. of liquid sulphur dioxide. The pyridine and methyl alcohol should be as free from water as possible.

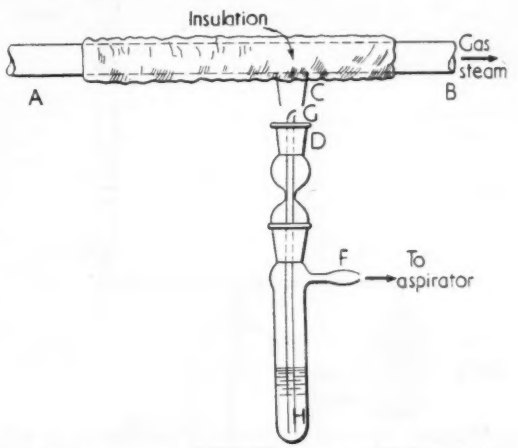

Fig. 2—Apparatus designed to sample hot gas without moisture-condensation

neck of the producer or where the gas sample is to be taken. The hole or tube through which the sampling tube is inserted is packed round with damp fireclay so that all the gas passes down the tube. The modified Drechsel bottle with a ground-glass socket *D*, matching *C*, can be plugged on to the sampling tube. After the stream of hot gas has raised the temperature of the sampling tube to above, say, 120° C., the Drechsel bottle containing about 1½ in. of pyridine (treated as described below) is fitted at *C* and a slow stream of gas is drawn through by means of an aspirator attached to the side-tube *F*. It is advisable to fit a small calcium chloride tube between *F* and the aspirator. The water from the aspirator is measured to give the volume of moisture-free gas passed through the pyridine. The fast stream of gas, by-passing the absorption bottle, maintains the temperature of the sampling tube well above the dew-point of the gas, and no condensation is possible except in the delivery tube *GH* or in the pyridine. Subsidiary experiments have shown that the pyridine in the Drechsel bottle is capable of absorbing all the moisture from any likely sample of moist gas without allowing any water to be drawn off by the gas stream. In practice, however, it would be advisable to fit a second Drechsel bottle containing treated pyridine to ensure that, in fact, complete absorption has been achieved. If there has been no decolorization of the contents of the second bottle, it is of course necessary to titrate only the first.

To conclude the description of the collecting technique, mention should be made of two devices which have proved useful. It is undesirable that the solution in the absorption bottle should become badly discoloured by too much tar. By partially closing the end *B* of the sampling tube, the flow of hot gas can be restrained sufficiently to maintain the temperature between the dew-point of the tar and the dew-point of the moisture. In this way a fractional separation of tar and moisture is effected in the sampling tube. The rate at which gas passes through the water-absorbing reagent is determined by the rate at which water runs from the aspirator, the exit tap being adjusted so that water flows from it at approximately 50–60 ml./min. Experience alone will tell to what extent the mouth of the sampling tube should be throttled to effect the desired fractional separation. Fitting a glass tube narrowed down to ¼-in. dia. generally proves satisfactory. The other device is that the end *G* of the delivery tube is bent over so that when the bottle is attached to the sampling tube this opening faces down stream to prevent its becoming choked with soot.

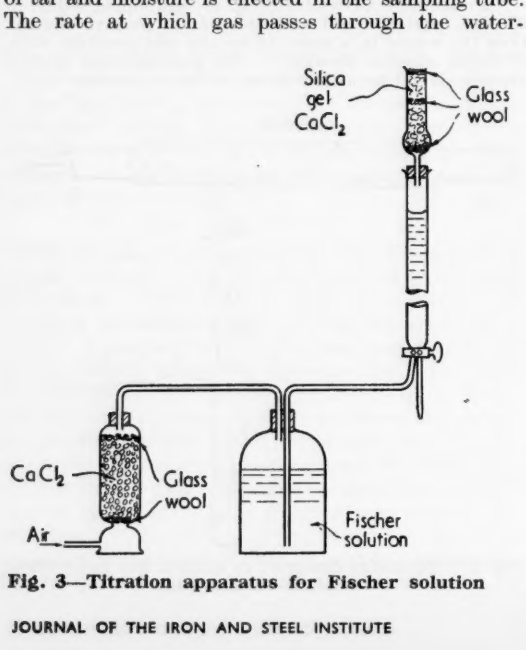

Fig. 3—Titration apparatus for Fischer solution

Procedure—The pyridine contained in the Drechsel bottle is titrated rapidly with Fischer reagent from an apparatus as depicted in Fig. 3. The reagent reacts with any water unavoidably present in the pyridine and turns the colour of the mixture to a bright yellow. When all the water in the system has been "neutralized" the next drop of reagent renders the mixture brown.* At this stage the delivery tube *GH*, complete with cap in socket *D*, freshly taken from a drying-oven and cooled in a desiccator, is fitted in place, and a dry rubber cap is placed on the side-arm *F*. At the producer site the cap is removed from *D*, and the rubber cap from *F*; the bottle is quickly attached to the previously heated sampling tube *AB*, and the requisite volume of gas is drawn through. This volume has usually been between 500 and 800 ml., but it depends upon the moisture content and to some extent upon the tar content of the gas. When the sample has been taken the caps are replaced on *D* and *F*, and the temperature of the water in the aspirator (*t*° C.) is observed.

In the laboratory the rubber cap is removed, and by judicious use of a small hand-bellows attached to the side-arm *F*, and manipulation of the cap on *D*, the pyridine is made to rise in *GH* to absorb any water condensed in this tube. The bellows are disconnected, and the delivery tube, etc., is removed, allowing as much as possible of the adhering solution to run back into the bottle. Whilst the solution is stirred gently with a small glass stirrer, Fischer reagent is run in from a burette till the brown end-point is noted. Working in front of an illuminated milk-glass screen facilitates the observation of the end-point. The volume of reagent required for this titration is noted (*R* ml.). A small glass capillary tube, holding a weighed amount of water, usually 50–60 mg., is dropped into the bottle, the contents are stirred, and the Fischer reagent is added till the end-point reappears. The second titre (*S* ml.) is noted. If *W* is the weight of water (in milligrams) in the capillary tube, the water content of the gas sample (*Q*) is *WR*/*S*. The moisture content of the gas is then calculated as follows:

18 mg. water vapour occupy 22·4 ml. at N.T.P.

Q mg. „ „ „ $Q \times \frac{22{\cdot}4}{18} \times \frac{(273 + t)}{273} \times \frac{760}{P}$ ml. at t° C. and at atmospheric pressure P mm.

If *V* is the volume of water from the aspirator, the

* If greater accuracy is desired a "dead-stop" electrometric method may be employed.

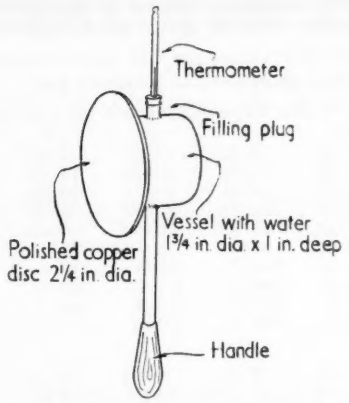

Fig. 4—Dew-point instrument

volume of gas in the aspirator, corrected for aqueous vapour pressure, is $V \times (P - p)/P$, where p is the partial pressure of water vapour in air saturated at $t°$ C. The proportion of water vapour in the producer-gas is given by :

$$\text{Percentage moisture by volume} = \frac{Q \times \frac{22 \cdot 4}{18} \times \frac{(273 + t)}{273} \times \frac{760}{P} \times 100}{\frac{V(P - p)}{P} + Q \times \frac{22 \cdot 4}{18} \times \frac{(273 + t)}{273} \times \frac{760}{P}}$$

Where great accuracy is not required, corrections for atmospheric pressure and water-vapour pressure can be neglected.

PHYSICAL METHODS

Dew-Point Determinations

A simple instrument[5] for the determination of the dew-point of the moist gas can be very easily constructed (*see* Fig. 4). It consists of a short length of brass tubing, 2 in. in internal dia. and closed at one end by a brass disc and at the other by a thinner disc of polished copper 3 in. in dia. The whole forms a shallow cylindrical vessel which can be filled with water through a small tube into which a thermometer is then fitted and sealed with a rubber sleeve. For comfortable handling it is advisable to braze a short handle of ¼-in. brass rod on to the cylinder.

The instrument, already filled with water, is placed in a steam jet or against a convenient hot surface to warm it to a temperature above the expected dew-point of the gas. A steel tube about 1 in. in dia., with one end closed to ¼ in. in dia., has its wider end inserted into the producer neck. The stream of gas soon covers the inside with a layer of soot and raises the temperature considerably above 100° C. By this means any chemical interaction between the material of the tube and the issuing gas is avoided and in addition there is no loss of moisture by condensation. The issuing jet of gas is now allowed to impinge on to the polished face of the instrument. If the temperature of the water is above the dew-point of the gas, no film of moisture will appear. The water is then cooled a degree or so and the jet again played on to the disc. This is repeated with frequent re-polishing of the surface until a moisture film momentarily appears ; the dew-point is then the thermometer reading. Tables are available[9] for converting dew-point readings to weight of moisture per unit volume of gas.

The condensation of tar on the polished face is at first disconcerting, but with a little experience the first moisture film can be detected quite easily. Frequent polishing is a great help in this respect. The authors have used this method simultaneously with their method described earlier and the following successive results show reasonably good agreement :

Water Vapour in Hot Raw Producer-Gas
(Volume Percentage)

By Dew-Point	By Authors' Method, Using Fischer Reagent
21	22·5
16·5	19
16	16
12·5	12
13·5	17
14	15·5
16·5	16·5
17	16·5
22	25
17	17·5
11	12·5

Because the absorption sample is taken over a period of about 10 min. and the dew-point method gives a spot value for the moisture content, exact agreement between the values cannot be expected ; the figures for the authors' method have not been corrected for atmospheric pressure.

The Pressure–Temperature Method

In the pressure–temperature method[8] (Fig. 5) a volume of the hot unsaturated moist gas is enclosed in a sealed vessel, and the temperature and pressure of the gas are noted. The vessel, still sealed, is then cooled considerably below the lowest possible dew-

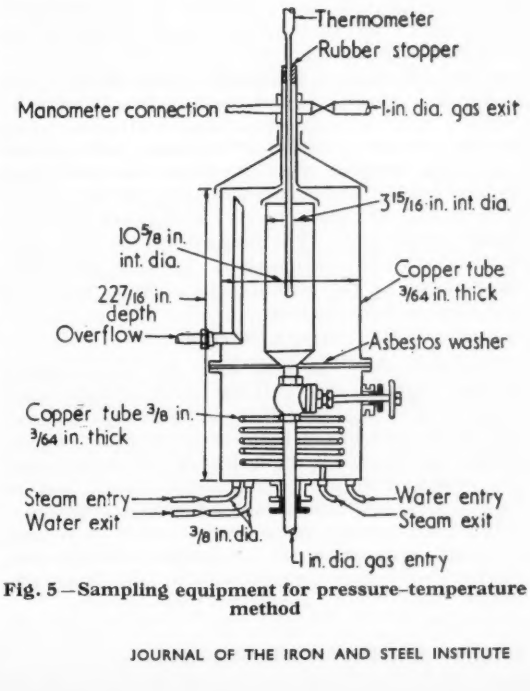

Fig. 5—Sampling equipment for pressure–temperature method

point of the gas, when the temperature and pressure are again noted.

Let $t°$ C., $t_1°$ C., p and p_1 be the initial and final temperatures and manometer readings respectively. The manometer readings are, of course, the algebraic excesses over atmospheric-pressure values, and if the barometer reads b mm. of mercury, then the absolute pressures P and P_1 are given by:

$$P = b + p \text{ and } P_1 = b + p_1$$

Let P_g and P_{g1} be the initial and final partial pressures of the gas. The saturated water-vapour pressure at $t_1°$ C. can be obtained from published tables. Let it be P_{s1}; then:

$$P_{g1} = P_1 - P_{s1}$$

Applying the equation of state, $PV = RT$:

$$\frac{P_g}{T} = \frac{P_{g1}}{T_1},$$

since the volume is the same in each case, T and T_1 being the initial and final temperatures in degrees absolute. Then

$$P_g = P_{g1}\frac{T}{T_1} = (P_1 - P_{s1})\frac{T}{T_1},$$

If the initial partial pressure of water vapour is P_s, then:

$$P_s = P - P_g = P - (P_1 - P_{s1})\frac{T}{T_1}$$

The proportion by volume of water vapour in the gas is P_s/P. Since 18 g. of water occupy 22·4 litres at N.T.P., the weight of water per cubic metre of gas at N.T.P is $804\ P_s/P$.

Procedure—The form of the apparatus used depends upon the nature of the gas to be examined; that shown in Fig. 5 is probably the most suitable for examining hot raw producer gas. This apparatus is not manufactured in this country, but its construction should not present undue difficulty. In the diagram provision is made for steam heating, but de Graaf[4] has suggested that this can be replaced by hot producer gas, in which case the spiral of copper tubing can be dispensed with and the inlets and outlets reduced in number. The hot gas is allowed to pass through and around the vessel in which the gas sample is to be enclosed, until a steady temperature is attained, when the inner vessel is sealed off by closing the proper taps. The temperature and pressure are read, and cold water is made to circulate through the outer vessel until the enclosed gas has been cooled below its lowest possible dew-point. The temperature and pressure of the gas and the atmospheric pressure are noted. Substitution in the formula given above will then give the moisture content.

CONCLUSIONS

The dew-point method and the temperature–pressure method are probably most suitable when "spot" values of moisture content are required. The former instrument is the easier to make and the quicker in use, but if the latter method is preferred, the construction of the apparatus should not be beyond the facilities available at most steelplants.

When an average value over a period of 10 min. or ¼ hr. is required, the absorption method using Fischer's solution is the most suitable. The apparatus can be made by any competent glass-blower.

APPENDIX—Moisture Content of Saturated Air at Atmospheric Pressure and Various Temperatures[9]

The following values may be used without serious error for fuel gases such as producer gas:

Weight of Water Vapour (grammes) in 1 cu. m. of Air

$t°$ C.	0	1	2	3	4
0	4·89	5·24	5·60	5·99	6·41
10	9·46	10·07	10·72	11·41	12·13
20	17·37	18·41	19·51	20·66	21·87
30	30·47	32·15	33·92	35·76	37·69
40	51·27	53·89	56·63	59·49	62·46
50	83·13	87·08	91·18	95·45	99·88
60	130·3	136·1	142·1	148·3	154·7
70	198·2	206·4	214·3	223·6	232·6
80	293·4	304·7	316·4	328·4	340·8
90	423·6	438·9	454·6	470·8	487·5

$t°$ C.	5	6	7	8	9
0	6·85	7·31	7·80	8·33	8·88
10	12·90	13·70	14·55	15·44	16·38
20	23·13	24·46	25·86	27·33	28·86
30	39·71	41·82	44·03	46·34	48·75
40	65·57	68·80	72·17	75·68	79·33
50	104·5	109·3	114·3	119·4	124·8
60	161·3	168·2	175·3	182·7	190·3
70	241·9	251·6	261·6	271·9	282·5
80	353·6	366·8	380·3	394·3	408·8
90	504·6	522·2	540·4	559·0	578·2

Weight of Water Vapour (pounds) in 1000 cu. ft. of Air

$t°$ F.	0	2	4	6	8
30		0·299		0·354	
40	0·414		0·480		0·553
50		0·634		0·725	
60	0·827		0·942		1·072
70		1·218		1·382	
80	1·566		1·772		2·001
90		2·255		2·536	
100	2·846		5·188		3·564
110		3·976		4·429	
120	4·925		5·467		6·058
130		6·70		7·39	
140	8·14		8·96		9·85
150		10·81		11·85	
160	12·97		14·18		15·48
170		16·88		18·38	
180	19·98		21·70		23·53
190		25·50		27·58	
200	29·81		32·17		34·69
210		37·36			

In producer-gas practice values of the saturation temperature usually vary between 30° and 45° C. (*N.B.*—Saturation temperatures such as those listed above must not be confused with the saturation temperature of the blast as recorded on the instrument attached to the producer.)

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IRON AND STEELWORKS ENGINEERING

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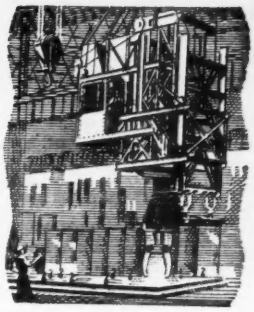


THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE SIXTH MEETING

THE SIXTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at 4, Grosvenor Gardens, London, S.W.1, on Wednesday, 18th February, 1948. Mr. W. F. CARTWRIGHT (Steel Company of Wales, Ltd.), Chairman of the Group, presided.

AT THE MORNING SESSION a paper on "Gaseous and Liquid Fuels in Iron and Steel Works," was introduced by the authors, Mr. J. B. R. BROOKE and MR. J. S. BRYAN. The proceedings of this session will be published in the September issue of the *Journal*.

AT THE AFTERNOON SESSION a paper on "Soaking Pits," was presented by the Society of Furnace Builders. The discussion, given below, was introduced by Mr. F. L. SMITH.

PROCEEDINGS OF THE AFTERNOON SESSION : 2.0 P.M to 4.30 P.M.

Discussion on SOAKING PITS*

The **Chairman** (Mr. W. F. Cartwright) : This afternoon we are having what is in the nature of a symposium on soaking pits. The paper,* which is submitted by the Society of Furnace Builders, will be introduced by Mr. Southern, and thereafter various speakers will talk about the different types of soaking pits described in the paper. Since the paper is by makers, I hope that after that we shall have some useful and constructive criticism by the users.

Mr. **H. Southern** (Chairman of the Society of Furnace Builders) : Towards the end of last year, a member of your Committee informed me that a paper on soaking pits and reheating furnaces would provide a needed basis for the discussion of important aspects of rolling-mill practice, and he wondered whether the Society of Furnace Builders would undertake its preparation. Let me assure you that the response to that suggestion was immediate. The Society, which represents the leading furnace builders of the country, at once appointed a committee to consider the form and scope of that paper.

When the committee met, it quickly realized that a single paper on soaking pits and reheating furnaces would cover much too large a field for consideration and discussion at one meeting of the Group ; and so, with the approval of your own Committee, it decided to submit a short symposium on soaking pits.

The first step was to approach the members of the furnace industry for information about their latest installations, to ask them for drawings and photographs, and also to request them to supply operating data. From the information thus supplied, the committee selected four contributions, each dealing with a soaking pit embodying a different principle of construction. It was felt that the distinctive features of each would provide an adequate basis for the discussion of soaking pits in general.

The result is that the paper as submitted, actually represents the opinions and the claims of four separate furnace builders upon the characteristics and the operation of the particular pits which they build. I should like that point to be appreciated ; each builder has expressed himself fully, and has freely described in his own words the pit which he manufactures.

The Society is very glad to have this opportunity of presenting this collective contribution to your proceedings and it hopes that there will be a free exchange of opinions upon the essentials of modern heating practice. Each contributor to the paper will present his own section, and, collectively, the furnace industry, which is fully represented here, will be glad to take part in the discussion.

Mr. **J. Buchanan** (Priest Furnaces Ltd., Middlesborough) then read the first section of the paper, relating to the reversing-type soaking pit. In doing so, he referred to the statement under "Fuel and Firing" on p. 127, that complete operating data were not yet available, and mentioned that since the paper was written he had been able to get figures of a test run to which he would refer later. Under the same heading, he called attention to a misprint in the penultimate

* *Journal of The Iron and Steel Institute*, 1948, vol. 158, January, pp. 125–137.

line of the first column, where " 16,000 cu. ft./ton." should read " 18,000 cu. ft./ton."

Dealing with the control equipment (p. 128), he said that there were other features, not referred to in the paper, which were of some significance. On the gas reversing valves, which were of the water seal type, limit switches were also fitted, so that the gas control valve could not re-open unless these had travelled the full distance. There was thus no chance of opening up gas to the pit with both valves open, or not in pre-arranged position.

Having read his section of the paper, he added: Just before leaving for London, we had some particulars of a test carried out on the pit as shown in Fig. 2, for condition (*a*) under " Fuel and Firing," *i.e.*, with twenty 4-ton cold ingots. The time taken to place all 20 ingots in the pit was 15 minutes and the period of test started from the finish of charging the last ingot. The gas during test averaged about 114 B.Th.U./cu. ft. Correcting to 100 B.Th.U. the gas consumption per ton of ingots came out at 16,500 cu. ft./ton, and the charge was heated in 6½ hr. The mean temperature of the ingots (ascertained by user) was just over 1200° C., and the results, generally, were good and the test acceptable.

From the figures obtained, the efficiency of this furnace comes out at 46·5%.

In starting up a unit like this, it is rare that minor troubles are not experienced. However, in this case, the only matter calling for comment is some slight air leakage and infiltration at the recuperator seating, which, apart from putting increased duty on the exhauster fan, is reflected in the efficiency. A further test will be run in the future when it is anticipated that accurate records indicating still higher efficiency will be available.

Mr. **J. W. Holden** (Salem Engineering Co., Ltd.), who was to have presented the section of the paper dealing with the circular soaking pit, was absent, so this section of the paper was read by Mr. H. Southern.

Mr. **C. H. Williams** (Stein and Atkinson, Ltd.) then read the section of the paper dealing with the one-way-fired soaking pit. He mentioned that the figures given in the last paragraph under " Fuel and Firing " (p. 133) were typical of weekly figures from customers' records.

Mr. **J. C. Hynd** (Wellman Smith Owen Engineering Corporation, Ltd.) presented the section dealing with the bottom-fired recuperative soaking pit. In the third paragraph of the section (p. 134) after reading the statement that " The ingots thus form a hollow square in the centre which in effect is a primary combustion chamber," he added that the height from the top of the ingot to the underside of the pit cover was approximately 2 ft. Under " Fuel and Firing " (p. 134), he mentioned that with new installations the quality of the fuel had a considerable bearing on the number of pits that would be required, as obviously with blast-furnace gas only, more pits would be required than for producer gas. In the last paragraph under this heading (p. 136), although the fuel rates given related to pits in the U.S.A., these were per British ton. When dealing with the recuperator (p. 136), he added that the cover carriage, which in some of the larger plants was of considerable weight, had its own independent rail girder supports, and therefore could not cause vibration of brickwork, and the cover in its closed position also rested on steel chains and not on the pit brickwork.

Mr. **F. L. Smith** (Dorman Long and Co., Ltd.) : I should like to congratulate the authors on a most interesting and informative paper. In comparing the four designs, the first thing that strikes one is the amount of opening of the doors required in some cases, to withdraw the ingots. I feel that there is still much to be said for the reversing pit of the first type described. There is a multiplicity of doors, and there may still be excessive repairs needed to the jambs of these; whether the designers have overcome that I do not know. It is possible, however, with this arrangement, to retain a relatively small opening for withdrawing the ingots.

In the second type, the circular soaking pit, you admittedly get a very fine heating effect, but you have a very large cover, and a comparatively cumbersome crane for lifting it clear; and when it comes to withdrawing ingots from the transverse axis you are forced to bring the lid back to well past the centre, which must mean quite a considerable heat loss. In respect of this type, I wonder whether the designers have given any thought to using a rotating lid with an auxiliary hole in it, which would have the effect of reducing this heat loss and, incidentally, would lessen the size of the crane required for lifting the lid.

Coming to the third type, the one-way-fired soaking pit, one's impression is that the far end of the pit will not get heated to anything like the same extent as the end nearest the burners. Perhaps the designer of this type of pit would like to say something about that. The doors, again, are heavy.

With the fourth type, the bottom-fired recuperative soaking pit, you have a large pit, and you again have to utilize a very heavy crane for lifting the doors. All these things, from the operating point of view, mean added maintenance and higher first cost. It would be interesting to know what the designers have to say on this subject.

Another question of interest is that of tonnage per square foot per pit as far as the space taken up in the building is concerned. The designers have not given any particulars of that, but a comparison in that respect would also be very interesting.

Mr. **J. Buchanan** (Priest Furnaces, Ltd.) : So far as covers are concerned, we do not want to make this subject controversial, but since the other types were referred to at greater length it is only fair that makers should present their views to Mr. Smith. On the question of space occupied, or output per unit of area, I do not think there is much to be said for any particular type of pit when compared with any other. If one wants to heat a specified tonnage, one has to reserve in the building a definite area to accommodate the same, and in many instances the shape of the pit chamber or tank is governed by crane approaches and other local conditions. If one has a rectangular pit, like that which was shown, it can be tucked against the main columns, but it is of necessity long. In other cases one can shorten the buildings and possibly widen the span. In the end, local conditions invariably govern these arrangements.

Mr. **C. H. Williams** : Mr. Smith asked about cover openings. The motorised coverings are a quick and easy means of charging and discharging the ingots. The amount of heat which is lost is actually very small, and it quite easily calculated. In view of the high speed at which these covers work (they work at nearly 100 ft./min.), the pit is open only for a few seconds.

I was asked about the heating of ingots in the long one-way-fired pit. I can only say that, contrary to what many people may imagine, it is the ingots at the far end which get heated first, not those nearest the burners; and it is the far ones which are charged first and discharged first, the others coming in their proper turn. The fact is that in a 25-ft. pit, as soon as the ingots are ready they can be drawn, and the near ingots will also be ready when their turn comes. The temperature of the

pit is taken from one point in the end wall of the pit, and the whole heat cycle of the pit is determined from that one point.

The motors on these lid machines are quite small. For a 15-ft. pit they are about 10 h.p., and for a 25-ft. pit they are about 20 h.p.

As far as tonnage per square foot of space in the building is concerned, I am afraid that I cannot give a figure, but it is well worth working out. I think that from the information given in the paper it will be found possible to work it out, but I will, if that is desired, give the figures in writing.

Mr. J. C. Hynd : I do not know that I can add a great deal to help, but I can quote figures on the actual heat-to-opening losses. With cold ingots the percentage loss is 2·6, and the heat to the steel is 54·8%. With ingots at 1200° F the heat to the steel is 45·9%, and the heat-to-opening loss is 6·7%. With a soaking pit of this type, which usually takes four ingots in width, the length can be 4 to 5 ft. greater than the width. It means that four ingots may be exposed, but with the fuel cut off, on the cover being moved you get a heat loss due only to the immediate effects of radiation. The cover carriages move at much higher speeds than the 100 ft./min. which has been quoted ; they travel up to 200 ft./min. No heat loss should be ignored, but from the figures quoted it will be appreciated that losses due to pit opening are not really considerable.

Mr. **J. W. Holden** (Salem Engineering Co., Ltd.) : This question of cover-opening heat losses has been raised with us many times. I think the answer is that with automatic shutting of the stack damper and automatic cutting-off of the fuel when the cover is lifted, such losses are definitely minimized. In reply to Mr. Smith's suggestion, we have considered a rotating lid so that we could open a smaller section, but the mechanics of rotation and sealing offer very many difficulties, particularly at the relatively high temperature at which pits are operated.

Mr. **R. Whitfield** (Incandescent Heat Co., Ltd.) : It is noted with satisfaction that the regenerative system is still worth consideration. When temperatures of 1200° C. and upwards are required then regenerators are worth more than a passing thought because of their latitude and flexibility.

The insulation of the movable covers is not common but worth consideration. These are at the top of the furnace and catch the brunt of the heat and bear a good proportion of the radiation loss ; the following figures will illustrate this :

Thickness Firebrick. in.	Thickness Insulation, in.	Heat Stored in all brickwork. B.Th.U/s q.ft.	Wt. all brickwork. lb./sq.ft.	Heat radiated, B.Th.U. s q.ft. /hr.
9	—	31,000	94	1700
9	2½	45,700	104	700
9	4½	50,300	113	490
—	9	15,000	38	470

It would be interesting to know the sizes of ingots, then practical data for heat penetration would reveal interesting and useful facts.

There is some useful information on scaling, but nothing about decarburization : has that proved a factor ? It is well known that CO_2 and N_2 are active decarburizers in the presence of superheated water vapour. This may not be of any practical importance in low-carbon ingots, but may have a major effect on the higher carbons. A decarburized layer often persists through later reductions. There are very active chemical reactions taking place during the process of combustion and their effects are little understood at present ; these reactions may cause metallurgical damage even in a reducing atmosphere, especially where the flame actually contacts the ingots. Truly neutral atmospheres are impossible in normal combustion. Blast-furnace gas comes nearest because of its low hydrogen, consequently, little water vapour is generated, which upsets the neutral equilibrium.

With reference to sand seals we find that this fine chrome ore to which Mr. Williams refers, ground to about 80–100 mesh, does far better than ordinary sand. It runs more like water, and it does not cake as ordinary sand does.

Mr. **D. C. Hendry** (Stewarts and Lloyds, Ltd.) : I should like to congratulate the various authors on the exhaustive way in which they have dealt with each of their particular types of soaking pit. It is very useful, but a little bewildering, because, as the Irishman said, "If there is any difference, they are all alike." I should like to have a little further information on the main points which concern all steelworks people in operation and maintenance ; the things that affect the burners and even the bottoms, walls, and roofs of the pits. I have had experience only of the regenerative type of pit in heating steel, but I should like to know more about the other types of one-way-fired pits.

I should like to know, also, whether, in quoting their heat consumptions per ton of hot and cold steel, the various manufacturers are referring to the net amount of heat consumed, or to the heat consumed, taken over a full week. We all know that pits must of necessity be kept alive during the week-end. Probably due to the manner in which the open-hearth furnaces, and so on, work, they may be charged with steel that is kept hot long before the mills are ready to turn over. That figure is of some importance to the people who are actually operating and maintaining these pits. Can the various makers, therefore, give us comprehensive figures for the heat consumption ?

As an example of what we can do, our figure varies from 1·4 to 1·6 million B.Th.U./ton of mixed charge per week, including the losses that take place at the week-ends. The proportion of cold steel averages about 14%. I should like to know from the operators of the various types of pit what their views on them are.

Mr. **H. Jones** (Salem Engineering Co., Ltd.) : Reference has been made to maintenance. I recently visited a steelworks where Salem pits were built in 1936, and the first main or general repair (which consisted of stripping the linings back to the casing) was carried out six weeks ago. The burners and the bottom portion of the front lining, also the waste-gas outlet flue, had been repaired on previous occasions, but this was the first general repair. The covers had ten years' life before a complete repair.

Mr. **J. Buchanan** : Unfortunately I cannot give Mr. Hendry maintenance figures for our installation, although his point about having over-all figures is appreciated. Those quoted were as given by our client for conditions determined as reasonable for an acceptance test. It was an entire cold charge and the test was organized and carried through by their technical staff. I shall, later, try to let him have detailed information on the lines suggested.

Mr. **C. H. Williams** : In reply to Mr. Whitfield's question about decarburization ; this is to a certain extent taken care of in most modern designs of pit by the amount of space given for combustion before the flame actually reaches the ingots. In other words, the flame is a fully combusted gas before it envelops the ingots, and, as the combustion is controlled, the

amount of decarburization on high-carbon ingots is very small indeed, and certainly not sufficient to worry the average mill operator. I think it will be found that where quality heating of quality steels is required, the new types of pit shown are proving very satisfactory.

Mr Hendry asked for practical figures of fuel consumption. The figures which we have given are actual weekly figures taken from normal records, not individual figures. In my section of the paper I gave two sets of figures, one set being weekly figures and the other individual heat figures. The weekly figures obviously vary from works to works, and depend to a very large extent on the manner with which the flow of ingots to and from the pits is dealt, and the heat of the ingots. It will be noticed that for a producer-gas-fired plant, hand controlled, I gave a weekly figure of 1·15 cwt. of coal per ton, with 53% hot, 16% black-hot, and 31% cold ingots.

Mr. **J. W. Holden** : The fuel figures which we quote are actually over-all figures, taking into account a whole week's operation ; but I think the fuel economy of any type of pit is more influenced by the flow of material from the casting shops, and any mill delays, than by standby losses. For example, it is possible to heat 90 tons of cold steel to "ready for rolling," in eight hours, but you cannot base an estimate of soaking-pit capacity on that figure and ignore the factors of flow of ingots from the melting shop, and the usual mill delays.

Dr. **C. H. Desch,** F.R.S. (President, The Iron and Steel Institute) : I should like to ask a question on the materials which are used in these refractory recuperators. Nothing is said in the paper about the materials, and, since I think that recuperative furnaces have a very great future if we can find suitable materials, I should like to know something about what has been used in these furnaces, and what kind of life has been obtained from them. At the National Physical Laboratory, when we built a recuperative furnace for very high temperatures—we wanted 1800° C.—we made our tubes of pure alumina, which stood very well, but that is rather too costly and difficult, perhaps, for large-scale operations.

If I may raise a point which struck me very much this morning, as well as this afternoon, cannot we get writers on subjects of this kind to agree about a scale of temperature ? We have Fahrenheit temperatures given here, and the paper this morning used Fahrenheit all through, except in one paragraph, where it used Centigrade. I have heard two speakers use Fahrenheit and Centigrade in the same speech. I have always looked forward to the time when the Fahrenheit scale would be as obsolete as the weights and measures of ancient Babylonia. After all, Centigrade is used by the whole scientific world ; it is international, and it is only in certain branches of industry in this country and America that we find Fahrenheit used. I have a good deal of trouble, in listening to discussions of this kind, in trying to translate the Fahrenheit temperatures to Centigrade.

That applies to certain other units as well. I am not referring to the question of the adoption of the metric system altogether, but to the very mixed units which are being used. That has not been so much in evidence this afternoon, but this morning we had different units for the quantity of dust per unit volume and for viscosities and so on, although we have internationally accepted units used by scientific men. I wish that industry would come into line with them.

Mr. **J. C. Hynd** : These recuperators in the bottom-fired recuperative soaking pits have been made in semi-silicon and also in high-alumina firebrick. It is essential in recuperation to have tubes or tiles of minimum thickness. No doubt further advances will be made with recuperators of, perhaps, different types in the near future.

In reply to Mr. Whitfield, I hardly think that it would be economical to use oil firing with the price still soaring, but, if it were, I would suggest that air should be used as the atomizing agent, and not steam. With open-hearth furnaces you are dealing with a special product, and the type and length of the flame required have made the steelworks engineer decide to go in entirely for steam atomizing ; but for reheating furnaces, and probably for soaking pits, I think that with efficient control air-atomizing would be satisfactory.

In reply to Mr. Hendry, the figures that I give are over-all figures per month, and take into account heat losses through pit opening and standing periods. There should be a set cycle arranged for charging and withdrawing, and that should be impressed on all steelworks engineers, particularly where you have large pits, which mean large doors.

Mr. **J. W. Reber** (Wellman Smith Owen Engineering Corporation, Ltd.) : I wish to express my appreciation of these papers, and to raise one point. The question of throughput per square foot of hearth area depends largely, of course, on the speed of heat transfer to the stock. Mr. Bryan this morning, in talking about the heating of coke ovens, mentioned that the blast-furnace gas gave a more even temperature. The only reason for that, is that there is a bigger volume of combustion gas per 100 B.Th.U. input. In the bottom-fired soaking pit there is a natural circulation of the combustion gases from the descending gases to the upflowing gases ; in other words, you increase the volume of combustion gases. Therefore the temperature drop of the gases from the bottom to the top of the pit is lower, resulting in a more even heat transfer along the length of the ingots.

The **Chairman** : I should like to mention something which Dr. Desch may have had in mind. I have recently heard that in Sweden (I do not know whether it was on the Salem type of round pit) the problem of how to get the gas down low enough in temperature to use metal recuperators has been overcome by the use of LaMont boilers. One drum for a set of soaking pits was used, and some LaMont coils were put in ahead of each metal recuperator, thereby lowering the temperature of the gas sufficiently so as not to damage the recuperator without injection of air, and having at the same time a highly efficient boiler.

It sounds a very good system, because every modern integrated steelworks still has use for low-pressure steam for space-heating, atomization of fuel oil, and many other jobs, and there is some room for heat recovery in the form of low-pressure steam. I understand that the installation operates very satisfactorily and that they are very pleased with it.

Mr. **J. W. Holden** (Salem Engineering Co., Ltd.) : I do not know the particular installation to which Mr. Cartwright refers, but we have a soaking pit in Sweden where they have put in a series of stainless-steel water-cooled tubes in the flue between the pit and the metal recuperators and obtained from this system the whole of the hot-water heating for their works offices. In the summer they use the hot water for feed water to their boilers. This system of waste-gas temperature dilution works perfectly satisfactorily and it is possible to recover approximately 2,000,000 B.Th.U. per hour by this method.

Dr. **A. V. Brancker** (British Iron and Steel Research Association) : As a comparative newcomer to the steel industry with but a recent acquaintance with soaking pits I could put a large number of questions to the authors, but will confine myself to a few elementary points. The first of these concerns the dimensions of a soaking pit relative to the size and number of ingots to be heated. I would suspect that there is some geometrical relationship between these factors, but there is no mention of this in the paper. The second question refers to the efficiency of soaking pits and Mr. Buchanan quotes a figure of 46·5% based on cold ingots. As, however, this 46·5% is a heat efficiency, and the ingots charged cold have lost heat to the atmosphere prior to charging, I do not think that the 46·5% figure is valid on an over-all heat basis.

Some emphasis has been put on the small temperature difference at the top and bottom of ingots after a soaking period, but I suggest that the criterion of good soaking practice is not the small temperature difference at the end of soaking but the time in which this is established. If, for example, an ingot remained two or three days in a soaking pit it may be expected that a very small temperature difference will be attained, but this means nothing. It is more important to know for a given soaking pit what the temperature difference is at different periods of the soaking process as a criterion of uniform heating.

The circular soaking pit seems to be a very attractive proposition, owing to the fact that you get turbulence and a circular motion of the gases, but it is not clear that this circular motion is based upon a pit containing ingots. I cannot quite see how the gas can go round two or three times in a pit if there are ingots present there, and these are staggered anyway. The ingots would have to be arranged tangentially to the flow of the gases for that assumption to hold good. In other words, considerable thought has been given, apparently, to the design of a circular soaking pit, but has this also included the arrangement of the ingots in the pit ?

Finally, and also in connection with circular soaking pits, what is the relationship between the height of the exit gas port and the dimensions of the pit in general ? Is there anything specific about this height ? It seemed from the illustration shown to be fairly close to the bottom of the pit. What would happen if it was at the top of the pit ?

Mr. **Buchanan** : I am afraid that I do not quite correctly understand the question. The efficiency figure given is arrived at from measurement of the heat input and the heat in the steel.

Dr. **Brancker** : You say that you have an efficiency of 46·5% based on cold ingots. I am taking into account the fact that those ingots were originally hot, and you have lost a certain amount of heat.

Mr. **Buchanan** : They were dead cold, taken from the stockyard.

Dr. **Brancker** : You cannot calculate that efficiency unless you take account of the fact that they have lost their heat first.

Mr. **Buchanan** : I will show you some figures later which will illustrate the point.

Mr. **Williams** : On the question of the top and bottom temperature, I should be very disappointed if ingots had to remain in our pits for two or three days. Sometimes they are there for only an hour, and they are uniformly heated if they are charged hot. If they are charged cold, they are uniformly heated in 7–8 hours, for an ingot of fair size.

It has been emphasized that there is considerable recirculation in these pits, and not only in the bottom-fired pit or the circular pit. There is recirculation round each ingot and at the back wall of the one-way-fired pit, and that recirculation does in fact give a very even heating of the ingot at all stages.

There are one or two other matters on which I should like to comment. Dr. Desch wanted to know about the material used for recuperators, and their life. When we had recuperators built right on the pit outlet they had about five years' life ; now that they are built leading from a flue connecting four pits the life is ten years. The material is not very special ; it is of the type generally known amongst us as about 44% of alumina.

As far as the geometrical position of the ingots is concerned, it is often the case that in a single works you have a very wide variety of sizes, sometimes ranging from one to five tons ; and obviously the pits are designed to suit as far as possible the most usual conditions in that works.

Mr. Cartwright referred to the use of metal recuperators, and to the necessity at present to protect them in some way by water or boiler tubes. I have seen the installation in Sweden to which he refers, and there is no doubt that it is working very well. We are at this time investigating an efficient metal recuperator which will not require any artificial means of cooling, but we are not ready to say much about that yet.

Mr. **Holden** : We have been utilizing, on a raw producer-gas-fired installation, metal recuperators which have had the outer needles removed and ¾-in. refractory sleeves dropped over the plain metal outside. The needles are still left on the inside. This arrangement has been quite satisfactory, but the difficulty lies in finding the correct type of refractory to withstand the chilling on the inside combined with the heat on the outside. Utilizing the same number of elements, we have lost only approximately 50° in preheat, owing to the incorporation of refractory sleeves.

I was asked how we charge the circular pit. With large ingots we charge it radially to the centre flue in one row and with smaller ingots we charge one row on the outside, and then an inner ring of ingots. We have operated with three rows of ingots in a pit of 16-ft. dia. perfectly satisfactorily.

Dr. **Brancker** : I am inclined to challenge the fact that you get uniform heating in the circular pit if your ingots are not arranged tangentially to the flow of the gases. I visualize the gases rebounding from one ingot to another.

Mr. **Holden** : I think you have not fully understood the principle of firing on the circular pit. The burners are set at a 37½° angle, and the products of combustion from one burner are picked up by the next. If you look into a circular pit when it is empty, you will see that each burner takes up and deflects the products of combustion from the next burner. As proof of this contention we would state that originally we built our pit with a small baffle wall in front of the burners, and this gave us a good deal of refractory trouble. We have now discarded this bridge wall as we find we do not need the baffle to protect the bottom of the ingots.

The **Chairman** : That does not really answer the question, which was how does the gas go round, if the ingots are in the way when you get up to the top ?

Mr. **Holden** : The ingots, of course, form a wall in front of the burners. The best answer I can give is that I have actually seen coke breeze being lifted off the bottom of the pit, due to the considerable spiral action from the waste gases. Some of the gas, of course, filters through between the ingots, but the majority spirals

up to the top and is then pulled down through the centre flue.

Dr. **Brancker** : I agree with you if you mean a spiral round the ingot.

Mr. **Holden** : Yes, round the ingots.

Mr. **H. H. Ascough** (Steel Company of Wales, Ltd.) : I should like to ask furnace designers present whether they have given thought to improving cover seals. My experience is that sand seals are very difficult to maintain, and failure in this respect results in frequent repairs to brickwork due to dry hot sand, almost fluid in its action, searching and packing into joints of the walls, etc. Chrome peas, as a substitute, are an improvement on sand.

Mr. Hendry asked for comments on the maintenance of soaking pits other than the orthodox regenerative type. So far as the one-way-fired pit is concerned, I have found that there is a tendency for make-up at the bottom of the recuperators, particularly with a three-way type of recuperator and producer gas as fuel. This leads to a marked falling off in furnace efficiency if allowed to carry on unchecked. On end pits of a battery the deposits can be cleaned out through a wicket in the end walls which should be provided for this purpose.

I notice from Fig. 6 that the cover is brought back on a gantry, and repaired in the back position which, of course, lays idle a valuable unit. Is it not better to take the cover off and replace it with a spare ? Obviously this question is related to the average life of a cover lining.

A further feature which requires improvement on this type of pit is again connected with the seal. If you again look at Fig. 6 you will see that there is a potential weakness over the gas port. It is extremely difficult to maintain a metal trough in this position, due to insufficient thickness of brickwork or insulation in the bridge.

Having pointed out one or two considerations connected with the one-way-fired pit, I should add that where limited space is available in relation to optimum soaking-pit capacity, this type has distinct advantages, and, subject to good maintenance, gives every satisfaction.

Mr. **C. H. Williams** : In reply to the first point, I agree that sand is not an ideal sealing medium, and we have used and recommend crushed chrome—I cannot tell you to what fineness, but to a grit fineness. It is definitely better than sand ; it does not cake, and it does not permeate the brickwork. The tops of our pits are different from those of which Mr. Ascough has experience, and are now made of overlapping refractory tiles instead of castings.

I agree that there is make-up at the bottom of the recuperators where these are built as one with the pit. With the new design that is taken care of, in that the dust is deposited in the flue leading to the recuperators. I say " new," and as far as this country is concerned it is fairly new ; two batteries of that design were built during the war and the recuperators have not given any trouble. Many more have been built abroad.

As far as lid repairs are concerned, if your crane is of sufficient capacity to lift the lid, that is the correct way to do it. Where you have a very big pit to hold a large number of ingots—say a 25-ft. pit—and your crane is designed to deal with 3-ton or 4-ton ingots, it is necessary to run the lid back into the lean-to ; but the life of the lid is long, and is certainly a matter of years.

There was a weakness over the gas port that has become apparent in Mr. Ascough's experience, but we have overcome that now. It is not really difficult to overcome.

Mr. **J. T. Davies** (Steel Company of Wales, Ltd.) : On three of the types of soaking pits described, great emphasis has been laid on the necessity for the installation of automatic temperature control, but in the first type of soaking pit described—the reversing-type pit—apparently the temperature control is manual, the operative being guided by an indicating pyrometer. I am wondering why this temperature indication with remote manual control is all that is considered necessary on this type of soaking pit.

Again one would have thought that with this type of pit which employs a metallic, needle-type recuperator, the absence of automatic soaking-pit temperature control would have made necessary the installation of automatic-recuperator maximum-temperature control. This does not appear to be provided.

Mr. **H. Jones** (Salem Engineering Co., Ltd.) : On the Salem pit the sand seal is a cast-iron trough 16 in. away from the inner face of the pit. Although sand is used as the medium for the seal, the fact that I have referred to linings which have been in since 1936, and I have also had experience of producer-gas-fired pits where the first complete lining was replaced last year after seven years' operation, shows that the sand seal problem on the Salem pit has been successfully overcome. The sand seal trough casting is carried on the main superstructure outside the steel casing and is not dependant on the walls for its support.

Mr. **L. H. W. Savage** (British Iron and Steel Research Association) : I should like to raise one point about the use of coke breeze on soaking-pit bottoms, which has been mentioned by three of the speakers. For the circular pit a figure is given of about 10 lb. of coke breeze per ton of ingots ; for the bottom-fired pit the figure is between 6 and 7 lb., while for the one-way-fired pit a figure of $1\frac{1}{4}$ tons a week is given, which at a very conservative estimate seems to be about $1\frac{1}{2}$ lb./ton, or probably less. That is quite a big variation in itself, but arising out of that I should like to know whether the heat of combustion of that coke is included in the heat required to heat the ingots. If you take 10 lb. of coke per ton, even with present-day coke, that is just over a therm.

I have two question to put to Mr. Buchanan. It would be of great interest to many people to have further details of the hot-gas reversing valve which he mentions. Secondly, has he found any difficulty with carburization of the metal recuperators with blast-furnace gas at 375–400° C. ? Many operators are scared about heating blast-furnace gas to very high temperatures.

The **Chairman** : I can answer the question about the coke breeze. It is pushed out at the bottom and is not burned.

Mr. **Savage** : If it is agreed that the coke breeze is merely pushed out at the bottom of the pits with the slag, and is not burned, the insistence by two plant manufacturers that the coke should have a high-fusion-temperature ash appears to be unnecessary.

Mr. **Holden** : The tendency is to go away from coke breeze entirely and use dolomite, crushed from $\frac{3}{8}$–$\frac{5}{8}$ in. in size. About 3–4 in. of dolomite is placed on the bottom, which is just ordinary firebrick quality, and something like 9–10 months' life is obtained before making a new dolomite bottom, although occasional fettling is necessary during this period, due to dolomite being removed on the ingot bottoms.

Mr. **Williams** : I have nothing to say on the breeze question, except that the figure which I have given works out at about 3 lb. of breeze per ton. The figure I gave is a practical working figure, representing the

amount of breeze put into the pit every 7–10 days. As far as the actual bottoms are concerned, there is a development in the U.S.A. in the use of dolomite, which I should like to look into further. I do not think that it is applicable simply to one particular design of pit.

Mr. **Buchanan** : I have consulted Mr. Priest on the question raised, as he has had a longer acquaintance with these metal recuperators than I. They have been in commission since 1938–39, and at the temperature stated we have experienced no difficulty at all.

Mr. **Savage** : I am rather puzzled with the figure given by Mr. Williams of 3 lb. of breeze per ton of ingots coupled with the total consumption of 1¼ tons of breeze per week. These figures correspond to a through-put per week of about 900 tons of ingots. The holding capacity, however, of these pits has been given as from 100 to 120 tons, which means that for normal six-day operation the average time per charge, including heating, holding, and idle time, will be of the order of 16 hr. My own estimate of 1½ lb. per ton had been calculated on the basis of an average time per charge of 8 hr.

Mr. **Williams** : In reply to Mr. Savage regarding coke breeze, the total quantity per 7–10 days is 1¼ tons = 2800 lb. Based on an output of 1000 tons per week for a 25-ft. pit, the consumption of coke is 2·8, say, 3 lb. per ton.

The figure of 1000 tons per week for the pit is a practical working one, and takes into account all operating conditions of the steelplant and the rolling mill. It is impossible to relate the plant output to heating times and holding capacity without knowing all the operating conditions which affect the weekly production.

Mr. **H. Southern** : The committee responsible for the arrangement of this collective paper believed that its presentation by different members of the furnace industry would be conducive to discussions of the widest possible nature. Many interesting points have certainly been raised and I should like to refer to one or two, as a designer of furnaces.

The paper describes a modern but conventional type of reversing pit in which horizontal streams of gases periodically alternate between a charge of ingots. It also refers to a tangentially fired circular pit in which the gases travel between the side walls and the charge, then encircle the ingots, and finally flow to a central outlet port in the hearth. In the third example, which is top fired from one end, the gases flow downwards in a horseshoe manner, thus enveloping the ingots before passing to a bottom outlet port below the burner. The fourth example is bottom-fired from the centre, and the gases flow upwards and then downwards, in fountain-like manner, between and around the ingots, before passing to outlet ports in the lower side walls.

Despite the different principles of operation it is interesting to note the similarity of performance in relation to heat consumption per ton of cold steel. One would have expected the over-all consumption of fuel to be noticeably affected by the differences in design, but I believe that the recent investigations of B.I.S.R.A., in relation to the performance of both soaking pits and furnaces, show that the attainment of fuel economy depends as much, if not more, upon correct control and operation than upon other influencing factors. Although this fact is realized by furnace builders, they constantly strive to minimize the effect of adverse operating conditions by innovations and improvements in the design and construction of their pits and furnaces.

The vital question of "pit capacity" in relation to "production requirements" was not raised, although the attainment of optimum operating efficiency depends upon a balance between the demands of a mill, and the characteristics, loading, and control of the soaking pits employed. All pits and furnaces give the best all-round results at a particular rate of production, under certain conditions of control, and the reasons for this phenomenon are constantly being sought. The differentiation of the many influencing factors is difficult, but there is evidence of a relationship between flame-swept wall surface and output for optimum conditions of operation.

An interesting point was raised by one speaker when he referred to the loss of heat from a large uncovered pit. It is known that the radiation of heat from a small hole in the side of a large flame-filled enclosure approaches that of a black body but, by comparison, the loss of heat from a 14-in. square hole in the side of a furnace with walls 14-in. in thickness is about 54% of that from a black body. The degree of thermal dissipation depends upon a radiation factor, and this is influenced by the shape and dimensions of the opening and the thickness of the wall. Let us assume, however, that the totally uncovered opening of a particular soaking pit is 200 sq. ft. in area, that the internal brickwork has a hot-face temperature of 2300° F., and an emissivity of 0·85, and that the factor of radiation is unity. Under these conditions the initial rate of heat loss would approach a theoretical maximum of 280,000 B.Th.U. per min. The rate of dissipation would decrease as the hot-face temperature of the brickwork dropped, but at 2000° F. it would still be 180,000 B.Th.U. per min. If the lid were kept fully open for 4 minutes per hour and thermal dissipation took place at an average rate of say 215,000 B.Th.U. per min., the total hourly loss, if usefully employed, would heat 1 ton of cold steel to rolling temperature. In practice, provided cold ingots were being heated, it is questionable if the actual average hourly loss, due to the influence of known and unknown factors, would reach 45% of the figure just calculated.

On the question of the thermal efficiency of soaking pits, the heat absorbed by one ton of steel when raised from atmospheric to rolling temperature is about 850,000 B.Th.U., so an over-all consumption of 1,700,000 B.Th.U. per ton represents an efficiency of 50%. At 1,600,000 B.Th.U. per ton of cold steel the over-all efficiency is about 53·2%.

CORRESPONDENCE

Mr. **G. W. Lake** (Shelton Iron, Steel and Coal Co., Ltd.) wrote : We have been given a most useful summary of the main features and performances of four quite distinct designs of soaking pit. Each of these types can be adapted for use with any one of the several fuels which are usually considered for the purpose ; and although they employ different methods of heat recovery from the waste gases, the heating times and thermal efficiencies appear to be very similar. From the thermal efficiency point of view, therefore, the best construction would be that in which the performance can be maintained over a long period with the least expenditure of time and money. Information on the cost of maintenance would be very valuable.

The most fundamental difference between the various designs is in the method of burning the fuel, and it does not follow that these are equally satisfactory because the heating times and thermal efficiencies are similar. The condition under which the heating is carried out is of first importance. The loss of metal due to scale formation, or washing the ingot, represents an easily computed charge that may even exceed the cost of fuel for heating. Disposal of the scale which falls into the pit also imposes limitations on the use which can be made of the pit. Moreover, as Mr. Whitfield emphasized in the discussion,

decarburization of high-carbon steels might be an important factor. It would seem that the best conditions should be obtained by providing complete combustion of the fuel before the fuel–air mixture comes into contact with the ingots heated, combined with accurate control of the fuel/air ratio. At first sight the reversing-pit design looks least favourable from this aspect, but in each of the others emphasis has been placed on the recirculation of waste gases which takes place. Addition of products of combustion to the fuel–air mixture must, however, reduce the speed at which combustion takes place, and may delay it so much that combustion is not complete before contact is made with the steel. Since it may not be possible to control the recirculation effect in the recuperative designs, the reversing pit may consequently be the best design in this respect, if provided with ample combustion space before the ingots.

Prominent mention is also made of convection as a means of heat transfer, but its effect can only be very small in comparison with that due to radiation under the conditions obtaining in a soaking pit. The main object must be to subject all the ingots equally, first, to the radiation from the high-temperature flame, second, to the radiation from the products of combustion. The main value of convection will be ensuring circulation of the products of combustion through all parts of the pit not occupied by the flame, so that the best use is made of their radiating powers.

In the reversing design, the pit is swept uniformly by the products of combustion, and the combustion itself is not retarded by mixture with waste products, but the radiation from the flame is not uniformly distributed. In the case of the bottom-fired soaking pit, it does not seem possible to avoid a fairly high velocity from the burner port in order to give the necessary turbulence to obtain quick mixing of the gas and air, and as a consequence of this the dilution of the flame with products of combustion would seem unavoidable.

Recirculation of the products of combustion in the flame can only be of value if the flame, without it, would be too short to give uniform radiation to all the ingots. The design in which this would seem most likely to occur is the long one-way fired pit, but in the discussion Mr. Williams stated that the furthest ingots became hot first. This suggests that a shorter flame would be beneficial, and therefore, that recirculation should be suppressed. It would be interesting to know whether this uneven rate of heating is equally pronounced in long as in short pits, seeing that they have been built from 9 ft. to 26 ft. in length. Where this uneven heating occurs, changing the position of the ingots in the pit, with its consequent delays, would also seem unavoidable and the makers' comments on this point would be interesting.

All the pits described make use of recuperators in one form or another. In this connection a very interesting design was described by H. Escher in his paper on "Developments in the use of Blast-Furnace Gas at the Port Kembla Steelworks."* An air recuperator for a ten-ingot pit which is only 4 ft. 6 in. long × 2 ft. 6 in. in dia., and can be used without diluting the waste gases with air, offers considerable advantages over existing designs. More should be heard of it.

Mr. **W. M. Barratt** (George Kent, Ltd.) wrote: After listening with interest to the papers, and the discussion which followed, there are just a few points I would like to raise, and I shall be obliged to the authors for their comments.

In each of the papers it was gratifying to hear that the control of temperature, pressure, and air/fuel ratio was accepted as an integral part of the furnace.

It appeared fairly obvious that the results obtained were satisfactory, otherwise some mention would have been made of any trouble that repeated itself.

After hearing of the different automatic controls on the reversing-type soaking pit, it came as a surprise to know that the temperature control was manual from the readings of an indicating pyrometer. Is there a particular reason for this? A method that is in current use, and successfully adapted to soaking pits, is to use a single-point temperature recorder of the potentiometric type connected to a thermocouple in the furnace and fitted with a pneumatic control mechanism. This mechanism is connected by air line to gas/air ratio indices in a ring-balance air-flow meter and a ring-balance gas-flow meter. Both these instruments are fitted with pneumatic control mechanisms which, through power units, transmit motion to valves in the gas and air lines. By the use of orifices in the gas and air lines, flow indications and recordings are available. In addition to these instruments a sensitive furnace pressure controller is fitted to control the pit pressure, and these pressures are indicated and recorded on a separate ring-balance meter.

With this method therefore, the temperature, air/fuel ratio, and furnace pressures are all under control, and readings and recordings taken of each. As all these instruments are flush-panel mounted in a cubicle-type panel, the arrangement is very informative, neat, and compact.

The author concerned with the circular soaking pit mentioned the position of the thermocouple as being set above one of the burners or alternatively in the waste-gas flue outlet. I presume that when it is fitted in the latter position, the fuel used is blast-furnace gas. The ± 10° C. uniformity mentioned was quite good.

I have in mind however that a variation may occur after the furnace has been in service for some time, and there is a possibility of any one burner's efficiency being reduced, so I would like the author's opinion whether the position of the thermocouple above one burner has proved to be the best. If it is practicable, does he think that an improvement could be made by inserting the couple in a position where the waste gas temperature is more average for all burners, and where any unburned gases near the burners have been combusted?

In references to the bottom-fired recuperative soaking pit, mention was made of the number of these furnaces in the U.S.A., and the temperature being Fahrenheit suggests that the method of control is American. It will be appreciated of course, that similar, or equally satisfactory control equipment can be supplied by English manufacturers.

As I have had no experience with these types of furnace, I would appreciate the opinions of the various authors on the types of thermocouples and protective sheaths that they find most suitable in each case. So much depends on the correct type of element, and protective sheath, when consideration is given to the corrosive and erosive action of the gases and the possibility of mechanical damage. These important points are very often neglected and the successful control of the whole furnace jeopardized.

The mention of Fahrenheit by Dr. Desch prompts me to state that in my experience of the temperature-measurement field, generally speaking, the use of this scale is made on boiler plants and power stations or in plant directly connected with American practice. As a general rule, industry in this country prefers to use the Centigrade scale.

* *Journal of The Iron and Steel Institute*, 1947, vol. 156, May, pp. 1–27.

The growing demand for indications and recordings of oxygen in furnaces is fully appreciated ; manufacturers are proceeding with research work, and it is hoped that they will be able to supply industry with suitable equipment within a short time.

AUTHORS' WRITTEN REPLIES

Mr. J. Buchanan (Priest Furnaces, Ltd.) wrote in reply : Mr. Barratt mentions temperature, pressure, and air/fuel ratio control in connection with each type of soaking pit, but it should be pointed out that the reversing, air-regenerative, gas-recuperative pit is not at present equipped with temperature control. Briefly, instrumentation is as follows :

(*a*) Operation of the main gas control valve by hand from the control panel. Movement of this valve can be effected by a hand wheel operating an oil pump or by selector switch and lever admitting oil under pressure from an electrically driven pump to the gas valve operating cylinder.

(*b*) A hydraulically operated butterfly valve in the air-supply main to furnaces operates in sympathy with the main gas valve (*a*), so as to maintain constant air/gas ratio.

(*c*) A butterfly of similar type in the exhaust system also functions indirectly in sympathy with gas control valve (*a*), to maintain steady conditions of pressure in the pit.

Other instruments included are :

(*d*) A 4-point temperature indicator and recorder for temperature of waste gases leaving regenerators, entering and leaving recuperator, and temperature of fuel gas leaving recuperator.

(*e*) A safety controller which rings an alarm bell and admits diluting air into the waste-gas stream, should the temperature of the products of combustion entering exhaust fan become unduly high.

(*f*) Furnace pressure recorder.

(*g*) Gas-flow indicator with integrator.

There should be no reason why, providing accurate and reliable temperature readings can be obtained from a thermocouple, these should not be applied to automatically controlled pit temperature. The main difficulty in the past, has not been that of controlling temperature, but of measuring temperature in view of the cost of rare metal couples, their relatively short life and occasional breakage. Standard of accuracy also tends to depreciate over the life of the couple.

With particular reference to the reversing pit, the application of temperature control is even more difficult, and, but for these inherent drawbacks, would no doubt have been fitted. It was only after much thought that it was reluctantly decided to omit temperature control, as it was felt that the system would not be sufficiently accurate or reliable for practical purposes.

The main difficulties are as follows :

(*a*) Determining a position in the pit for the thermocouple which will not be affected by fluctuations in temperature over the reversal period or by the shielding effect of placing cold ingots in the pit. A method previously employed, is to insert a couple through the furnace side wall in a refractory sleeve with a thin, solid end. The temperature thus obtained would not be an accurate measurement of pit temperature but could be regarded as comparative, *e.g.*, by trial and error it may be found that to maintain pit temperature at, say, 1340° C. the temperature reading as measured by the thermocouple may be equivalent to 1280° C. The control point is therefore set at 1280° C. to ensure a furnace temperature of 1340° C.

(*b*) These couples made from rare metals with a platinum base, usually platinum, and an alloy of platinum and rhodium, are expensive. In some works, employing their own staff for salvaging burned portions of thermocouples and re-welding into new units, this expense is greatly reduced.

There has been a great call over the last few years for an instrument continuously measuring and recording the presence of oxygen in furnace gases, and, although several of these are on the market, they have certain limitations, principally, we understand, in the lag which occurs between taking a sample and recording it. At the Appleby pit, frequent measurements are taken by the " Orsat " apparatus, and a continuous check kept on the operation of the pit by the Fuel Research Department. Any leaks or positions where air infiltration could take place are investigated and steps taken to make these good. It is found that over the normal range of operations, with the instrumentation provided, loss of efficiency and deleterious effects on the ingots due to excess oxygen in the furnace gases can be maintained within very small limits.

In reply to Mr. Lake on the question of thermal efficiency, there should be little variation on the four pits as described. When using similar fuel, the degree of pre-heat (*i.e.*, recovery from waste gases), intimate mixing, and combustion arrangements are about the only factors which are variable.

The point raised regarding the best method of construction being that where the performance can be maintained over a lengthy period with least expenditure is of considerable importance since, as mentioned, one form of construction may answer very well for a limited period, the user thereafter being involved in higher production cost. At present, the units constructed at Appleby have been in use for several months only, and although maintenance records would be available from previous installation, it will naturally be some time before corresponding figures are available for the more recent soaking pits.

Remarks on heating conditions are noted, and it is agreed these are of prime significance, and while alive to the appreciable losses incurred due to scale formation, or washing the ingot, this is a complex subject and demands continued investigation by the designer and mill operator jointly.

From choice the engineer would, of course, prefer when building modern pits that they form part of a complete new scheme. In many cases, however, existing buildings and ingot-handling machines impose restrictions on furnace design from the outset.

Mr. **J. W. Holden** (Salem Engineering Co., Ltd.) wrote in reply : Mr. Barratt's suggested alternative position for the thermocouple controlling the temperature on a circular soaking pit in the waste-gas flue outlet, is not dependent on the type of fuel which is being used. For example, a thermocouple in this position has been used on an oil-fired pit, a mixed blast-furnace and coke-oven-gas-fired pit, and a producer-gas-fired pit, but not on a blast-furnace-gas-fired pit.

With regard to the position of the thermocouple in the pit proper, this is not placed over one particular burner, but between, and above, any two adjacent burners, and we have not found that changes in burner efficiency have affected the control of the pit. The greatest danger with the thermocouple in this position is that on changing the thermocouple, due to failure, it is important that the thermocouple end is allowed to protrude the same distance from the face of the brick side-wall lining. Obviously, if this overhang varies there is a

tendency for differences between the temperature registered by the thermocouple and that of the ingots.

We ourselves prefer the thermocouple to be in the waste-gas flue where it is not affected by radiation or the relative positions of the ingots in the pit, but some people object to this, due to the fact that it is not so easy from a maintenance angle to have the thermocouple in this position.

If the control of pit temperature is from a thermocouple in the waste-gas flue, however, we prefer, in addition, to have an indication from a thermocouple in the pit itself, as this keeps a check on the brickwork temperature of the pit.

With regard to the question of protective sheaths for thermocouples on soaking pits, it is the writer's experience that the best results are obtained from an inner sheath of sillimanite with an outer sheath of carborundum.

In reply to Mr. Lake's comments, as far as the circular soaking pit is concerned there is no addition of the products of combustion to the fuel–air mixture, and we feel that Mr. Lake has misunderstood our reference to the recirculation of waste gases.

The correct amount of air and gas for combustion is automatically controlled and supplied to the burners, and our reference to the recirculation of waste gases means that after combustion at each separate burner, the products of combustion travel round the pit, enveloping the ingots, before eventual evacuation at the waste-gas outlet. With this rapid movement of combustion products around the ingots, convection heating must have a considerable amount to contribute to the transfer of heat, in addition to the radiation transfer.

Mr. **C. L. A. Webb** (Stein and Atkinson, Ltd.) (in the absence of Mr. C. H. Williams) wrote in reply : Mr. W. M. Barratt raises the point of temperature control of the pits being manual instead of automatic. As far as the one-way-fired pit is concerned, when this is fitted with control equipment fully automatic control of temperature is included, variations of temperature being used as a medium for controlling the gas flow, which is in turn measured and proportioned to the air flow.

The type of temperature-measuring device used can be a double-sheathed platinum/platinum–rhodium couple, or a radiation-type pyrometer focused on a disc, which in either case is situated in the end wall of the pits opposite the burner and between the rows of ingots. In this position a normal life of the temperature-measuring device is experienced and there is little likelihood of damage from the ingots. A platform is generally provided along the outside of the pits for easy maintenance.

Mr. G. W. Lake, emphasizes a salient point, in that the condition under which the heating is carried out is of first importance. In one-way-fired pits, combustion is completed above the top of the ingots ; hence only products of combustion envelop the ingots, and, as is well known, fully combusted gas has a far less deleterious effect on them than partially combusted gas or stratified gas and air streams. Furtner, the burner is designed to suit the particular fuel to be used, with the object of obtaining completed combustion above the ingots. A feature of these pits, which is, of course, a function of the position of the burner and the combustion obtained, is their ability to hold ingots at temperature for long periods without undue increase in scale losses and without washing the surface of the steel.

On the question of decarburization of high carbon steels, atmosphere control plays the most important part, emphasizing the necessity for automatic control.

In connection with the question of the ingots farthest from the burner being heated more quickly than those adjacent to the burner, this is relative only, and in practice the temperature difference is much less marked as the temperature increases to that required for rolling. There is never any necessity to change the position of the ingots in the pits. Experience shows that by the time the ingots remote from the burners are ready to be drawn, those at the opposite end of the pit are up to temperature. As is often the case in industrial development, early pits of this design were built quite short and as increased ingot capacity was required the pits were lengthened. It is not yet known if the maximum length has been reached, but again experience has shown that the longer pits, in addition to having increased ingot capacity, have the ability to heat ingots uniformly and more economically in fuel consumption.

Mr. Lake draws attention to the metal recuperator designed by H. Escher at Port Kembla. It is that recuperator which the author had in mind when replying earlier in the discussion to a comment by the Chairman. Since the meeting he has personally investigated this type and finds that its claims are well justified in practice.

Mr. Smith enquired regarding pit tonnage related to space taken up in the building. The installation shown in Fig. 6 has an effective pit area of 3000 sq. ft., and the total space taken up in the pit bay between crane rails is 50 ft. by a length of only 240 ft. Under average British conditions of mill operation, and supplies of hot and cold ingots, the output is 16,000 to 19,000 tons per week. The pit output/week/sq. ft. space is thus 1·3 to 1·6 tons.

Mr. **J. C. Hynd** (Wellman Smith Owen Engineering Corporation, Ltd.) wrote in reply : It should be pointed out to Mr. Lake that the burner port of the bottom-fired recuperative pit is so designed that combustion takes place within the port and therefore the flame is of minimum length. The gases flow along the length of the ingots without impingement on the ingots and it will be appreciated that this method of firing is very desirable, especially on hot ingots. In the case of the small percentage of cold ingots which are charged at week-ends, the rate of heat input into the pit can be controlled so that the cold ingots are heated evenly, and at no time is it necessary to change the position of the ingots in the pit.

When heating special steels, the temperature differential betwen the ingots and the pit must be carefully watched, as obviously if a cold ingot of hardened steel was placed in a hot pit, severe stresses would be caused in the ingot, and likewise with hot high-carbon steel ingots having a track time of 2½ to 3 hr., the pit temperature should be dropped to 1800° F., before the ingots are charged.

In reply to Mr. Barratt, it should be mentioned that instrumentation of soaking pits has been very successful on the bottom-fired recuperative pits installed in the U.S.A., and with the essential instruments now available in this country, there is no difficulty in applying these, including pit temperature and pressure control.

On this pit there are usually two thermocouples in the top wall of the pit between the top of the ingot and the cover. These act as temperature limit controls and, in addition, there are four thermocouples, one in each corner of the pit in the exhaust-gas outlet flues to the recuperators. These are of platinum/platinum–rhodium, shrouded in sillimanite and have a silicon-carbide sheath. sheath.

Each of these thermocouples is connected to a 4-point recorder and has a selector switch so that any thermocouple can be connected direct to the controller which operates the valve, either on the air or the gas line.

N E W S

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Special Summer Meeting in Norway, 1949

The Council has received an invitation from the Norwegian Metallurgical Society (Norsk Metallurgisk Selskap) and representatives of the Norwegian metallurgical industries to hold a Special Summer Meeting in Norway in 1949. It is hoped that this Meeting will take place from Saturday, 28th May, to Tuesday, 7th June, 1949.

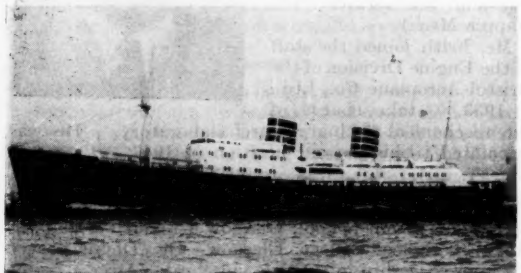
The Bergen Steamship Co., Ltd., has kindly offered to make M.S. *Venus* available for the Meeting. The *Venus* is a fast, comfortable ship of 7000 tons with a capacity for over 350 passengers. She will sail from Newcastle on the evening of 28th May, and return there on the morning of 7th June, 1949. It is proposed that Members and Ladies should live on the ship throughout the Meeting.

The programme will probably consist of two days in Oslo, thence proceeding by sea to Kristiansand, Tyssedal and Odda in the Hardangerfiord, Bergen, and to various places in the Sogniafiord. There will be a meeting for technical discussions in Oslo; there will also be vists to works in Oslo and at other places where the managements have kindly agreed to give facilities for Members to see some of the largest and most modern furnaces for the electric smelting of iron, steel, and ferrous alloys, as well as important zinc, nickel and aluminium plants, power stations, etc. There will, in addition, be excursions for the Ladies.

The inclusive cost of the Meeting will vary between about £55 and £85 per person, depending on the type of cabin selected; most of this will be payable in sterling.

Members will appreciate that it is necessary for the Council to have an indication of the numbers likely to take part in the Meeting before completing the shipping arrangements. A notice giving full particulars will therefore be sent to Members inviting them to register during the autumn of 1948, and to pay a deposit of £10 per person on registration.

This preliminary announcement has been issued in the hope that it will help Members to decide in advance whether they intend to take part in the Meeting.



M.S. Venus

Annual General Meeting, 1949

The Annual General Meeting of The Iron and Steel Institute will be held in London on Wednesday and Thursday, 27th and 28th April, 1949. A Luncheon for Members is to be arranged for Thursday, 28th April, 1949.

Changes on the Council

Mr. GERALD STEEL has been nominated a Vice-President of The Iron and Steel Institute and Mr. W. BARR becomes a Member of Council. Mr. A. H. GOODGER has agreed to serve as an Honorary Member of Council during his presidency of the Manchester Metallurgical Society.

Andrew Carnegie Trust Fund

Grants have been made by the Andrew Carnegie Trust Fund to the following:

(1) Mr. LICHANG HSU: £250 for research at Sheffield University on the constitution of quenched, annealed, and cold-worked carbon and alloy steels.

(2) Mr. R. GUENOT: An extension of a grant for six months (£100) for the continuation of a research at Sheffield University on the electrical properties of cold-worked metals and alloys.

(3) Mr. E. T. TÜRKDOGAN: £250 for research at Sheffield University on slag–metal reactions.

Seventy-Five Years Ago

The main social event at the Liége meeting of The Iron and Steel Institute (1873)—the Institute's first foreign meeting (*see* "Seventy-Five Years Ago," on page 315 of the July, 1948, issue of the *Journal*)—was the banquet given by the Reception Committee. At the conclusion of the dinner, M. Trasenster, who presided, proposed the toast of the King of the Belgians and announced that His Majesty desired to show his friendship for the representatives of the English iron and steel industry by inviting them all to his palace on the following day. The toast was most enthusiastically drunk, and when the acclamations had ceased, the band struck up the Belgian National Anthem, "La Brabançonne."

M. Pierot, the Burgomaster of Liége, next proposed the health of the Queen of England. The toast was drunk with so much applause that, according to the *Journal de Liége*, "it made the vaults of the vast room shake, and it was a long time before silence was restored."

M. Trasenster, the Chairman of the Reception Committee, followed with the toast of the evening, "The

Iron and Steel Institute of Great Britain." In proposing the toast, he said that it was a great honour for the Committee to receive at that meeting so many earnest, practical, and learned men from England. "In running over the list of members of this Institute," M. Trasenster continued, "we are struck with this feature, that Englishmen know how to be rich. They can possess riches without being wholly possessed by them. With fortunes which would be colossal with us, you continue to devote yourselves to business, you honour it, you devote yourselves to scientific labours, to useful institutions; and in England, as in America, one sees what is altogether an exception on the Continent, enormous sums of money applied with intelligence by private parties to benevolence, to instruction, to hygienic purposes, to every art, and to every useful industry. Everywhere one meets with public buildings erected by private means."

The toast having been drunk with acclamations, Mr. I. Lowthian Bell, President of The Iron and Steel Institute, responded. He said that he was so much taken aback by the hospitality and goodwill which he experienced on every side that he begged leave to reply in his native language. Having returned, on behalf of the members, their most profound and grateful thanks, the President proposed success to the iron trade of Belgium. He said, "We live in eventful times; the eastern world, which hitherto has kept itself more or less aloof from the west, that is to say, from civilization, seems to be awakening to its position. We have in late years been visited by the sovereigns of Turkey and Egypt, and more recently the Shah of Persia has broken through the tradition of centuries, and has been our guest. In the advantages to be derived from these humanizing influences, Belgium will, as she deserves, receive her share; of this no one can doubt who visited, as I have done, the great establishments of Sclessin, Seraing, and others."

NEWS OF MEMBERS

▶ Dr. D. P. ANTIA, Honorary Secretary of the Indian Institute of Metals, has changed his address to 102A, Netaji Subhas Road, Calcutta.

▶ Mr. G. BARBER is leaving the English Steel Corporation, Sheffield, to take up a position in the laboratory of the Jarrow Metal Industries, Ltd., Jarrow.

▶ Mr. FRANCIS D. BRIDGE has left Messrs. Wm. Beardmore and Co., Ltd., Glasgow, to join the staff of Messrs. Guest, Keen and Nettlefolds' Research Laboratories, as senior research officer in their Metals Division.

▶ Mr. I. N. GANDHI is now works manager at Messrs. Burn and Co., Ltd., Howrah, Bengal.

▶ Mr. RAYMOND HAYNES has been awarded the degree of B.Met. with first-class honours in non-ferrous metallurgy. He has also been awarded by Sheffield University the Mappin Medal, for metallurgy, the Nesthill Medal, for non-ferrous metallurgy, and a George Senior Research Fellowship in metallurgy.

▶ Mr. T. B. V. HIRST is resigning his position with De La Rue Gas Development, Ltd.

▶ Mr. T. KO has been appointed lecturer in metallurgy at Birmingham University.

▶ Mr. P. L. J. LEDER is to take up an appointment with Messrs. G. A. Harvey (London), Ltd.

▶ Mr. CLIFFORD C. MORGAN has left Messrs. David Brown and Co., Ltd., to join the staff of Messrs. Guest, Keen and Nettlefolds, Ltd., at Cwmbran, as foundry metallurgist.

▶ Mr. ARCHIBALD PREECE has been appointed Professor of Metallurgy at Durham University, in succession to Professor C. E. Pearson.

▶ Mr. PETER E. SEMLER has joined the wire-mill staff of the Canada works of the Steel Company of Canada, as project engineer.

▶ Mr. W. M. SERVICE, previously works manager and a Special Director at Messrs. Wm. Beardmore and Co., Ltd., has joined the Board of Messrs. Mechans, Ltd., Glasgow, as Technical Director.

▶ Mr. EARLE C. SMITH, chief metallurgist of the Republic Steel Corporation, Cleveland, U.S.A., has been selected for the award of the Benjamin G. Lamme Medal for eminence in engineering.

Obituary

The Council regret to record the deaths of:

Mr. HARRY BREARLEY, on 14th July, 1948, at Torquay, aged 77.

Mr. F. F. GORDON, Managing Director of Spear and Jackson, Ltd., Sheffield, aged 61.

Mr. JAMES H. HERRON, of the James Herron Company, Cleveland, Ohio, U.S.A., on 29th March, 1948.

Sir CLIFFORD PATERSON, F.R.S., Founder and Director of the Research Laboratories, General Electric Co., Ltd., Wembley, Middlesex, on 26th July, 1948.

CONTRIBUTORS TO THE JOURNAL

Ronald Toye, B.Sc., A.M.I.E.E., A.Inst.P.—Senior scientific officer in the Steelmaking Division of the British Iron and Steel Research Association. Mr. Toye graduated at University College, Swansea. From 1936 to 1940 he was a member of the geophysical staff of the Anglo-Iranian Oil Co., Ltd., and during this time was engaged in oil prospecting in Persia and in England; he was associated with the discovery of the oil field in Nottinghamshire. During the recent war Mr. Toye served in the R.N.V.R., with the rank of lieutenant. He joined the British Iron and Steel Research Association in 1946 and is stationed at Sketty Hall, Swansea, where he is responsible for the electric steelmaking section and for field trials.

P. H. Frith, A.Met., F.I.M.—Research metallurgist and assistant chief metallurgist to the Bristol Aeroplane Co., Ltd., Engine Division. Mr. Frith joined the staff of the English Steel Corporation in 1924, and served in the rolling mills and the research laboratory, where he was engaged in research on metallography, works observations, and mechanical testing. In 1929 he obtained the degree of A.Met. at Sheffield University and was awarded the Mappin Medal.

Mr. Frith joined the staff of the Engine Division of the Bristol Aeroplane Co., Ltd., in 1933, to take charge of the mechanical-testing research laboratory. He was appointed to his present position in 1947.

H. A. Dickie, D.Sc., Ph.D., F.I.M.—General manager of research, Messrs. Stewarts and Lloyds, Ltd. Educated at Glasgow High School, Glasgow University, and the Royal Technical College, Glasgow, Dr. Dickie served his apprenticeship in a Clyde shipyard. After a period of military service from 1914 to 1919 he took up metallurgy and graduated B.Sc. in 1923 and received the

A.R.T.C. in 1925. He was then awarded a Carnegie Research Scholarship and a Carnegie Research Fellowship and received the degree of Ph.D. in 1927 and the D.Sc. in 1930. In that year he joined the research department of Messrs. Stewarts and Lloyds, Ltd., where he has been successively in charge of metallurgical, chemical, and general research.

S. J. Tupper, M.A.—Senior experimental officer, Ministry of Supply, Fort Halstead, Sevenoaks. Mr. Tupper was educated at the Polytechnic, and at University College, London, where he graduated with first-class honours in mathematics. Before the recent war he was engaged in work on aerodynamics and ballistics, but later transferred his attention to problems bearing on the design of guns and projectiles. He is now concerned with fundamental solid mechanics and the plastic flow of metals.

R. Hill, M.A., Ph.D.—Engaged in research on plastic flow for the British Iron and Steel Research Association at the Cavendish Laboratory, Cambridge. Dr. Hill was born in 1921 and educated at Leeds Grammar School and at Pembroke College, Cambridge, where he was awarded in 1942 the degree of B.A., and the M.A. in 1945. He has recently gained the degree of Ph.D.(Cantab.). From 1941 to 1943 he worked under Professor J. E. Leonard-Jones in the Mathematics Laboratory, Cambridge, on the theory of internal and external ballistics. In May 1943 he joined the Armament Research Department at Fort Halstead, Kent, working under Professor N. F. Mott, F.R.S., on theoretical problems connected with armament research. Dr. Hill began research at the Cavendish Laboratory, under Dr. E. Orowan, F.R.S., in 1946, and joined B.I.S.R.A. in 1948.

IRON AND STEEL ENGINEERS GROUP

Eighth Meeting

The Eighth Meeting of the Iron and Steel Engineers Group will be held on Wednesday, 24th November, 1948, at the offices of the Institute, 4, Grosvenor Gardens, London, S.W.1. Three papers on the handling of materials in iron and steel works will be presented and discussed.

BRITISH IRON AND STEEL RESEARCH ASSOCIATION

Scientific Advisory Council

The Director of the British Iron and Steel Research Association has accepted an invitation from the Ministry of Fuel and Power to serve on a Scientific Advisory Council which is being set up to advise the Ministry on scientific problems connected with all sources of fuel and power, to co-ordinate development in the different industries now controlled by the Ministry, and to indicate problems needing scientific investigation.

Students' Exchange Scheme

Arrangements have been made for three foreign students (two from Switzerland and one from Sweden) to work for about nine weeks at the Research Association's Physics Laboratories at Battersea. They will be visiting this country through an international exchange scheme arranged by the Imperial College of Science and Technology.

Junior Steelmaking Conference

At the Junior Steelmaking Conference of the British Iron and Steel Research Association, held at Ashorne Hill, on 23rd and 24th June, 1948, talks were given on "*The Managerial Control of the Open-Hearth Furnace and its Relation to Furnace Design*," and on "*The Manufacture of Large Ingots (over 100 tons)*." The papers gave rise to vigorous discussion. The attendance (limited to steelworks personnel who do not normally attend the ordinary Steelmaking Conferences) numbered over sixty.

Staff

Mr. K. A. PYEFINCH has left the Marine Biological Station at Millport to take up an appointment with the Scottish Home Department, at Edinburgh.

AFFILIATED LOCAL SOCIETIES

Swansea and District Metallurgical Society

The list of Council and Officers for the 1948–49 session is as follows:

President-Elect

T. J. CANNING

Vice-Presidents

M. L. HUGHES, M.Sc., F.R.I.C., F.I.M.
R. GRIFFITHS, M.Sc., F.I.M.

Honorary Treasurer

U. WILLIAMS

Members of Council

D. L. BLEWITT
H. N. BOWEN
R. G. DAVIES
R. W. EVANS, M.Met.
F. MILLS, M.I.Mech.E.
D. G. NEWMAN
M. J. A. THOMAS, B.Sc.
R. WALKER

Honorary Secretaries

L. PERRETT, F.I.M.
H. A. COOKE

Representation of the Institute

Ebbw Vale Metallurgical Society

Mr. R. A. HACKING has agreed to represent the Institute on the Council of the Ebbw Vale Metallurgical Society.

Manchester Metallurgical Society

Mr. J. SINCLAIR KERR has agreed to represent the Institute on the Council of the Manchester Metallurgical Society. As already announced, this Society became affiliated to the Institute on 1st June, 1948.

INSTITUTE OF METALS

Autumn Meeting at Cambridge, 1948

The Autumn Meeting of the Institute of Metals will be held at Cambridge from Tuesday, 14th September, to Friday, 17th September, 1948. An outline of the programme is as follows:

Tuesday, 14th September

2.0–6.0 P.M.: Secretary's office will be open at the Arts School.
6.30 P.M.: Service in the Church of St. Edward, King and Martyr.
8.0–11.0 P.M.: Conversazione in the Old Schools.

Wednesday, 15th September

9.45 A.M.–12.45 P.M. : Business meeting and presentation and discussion of the following papers :

(1) E. W. TAYLOR : "The Micro-Hardness Testing of Metals."

(2) G. A. COTTELL, K. M. ENTWISTLE, and F. C. THOMPSON : "The Measurement of the Damping Capacity of Metals in Torsional Vibration."

2.0 P.M. : Works and other visits for members and ladies.

7.0 P.M.–midnight : Supper-Dance at the Guildhall.

Thursday, 16th September

9.45 A.M.–12.45 P.M. : Presentation and discussion of the following papers :

(1) J. S. BOWLES and W. BOAS : "The Effect of Crystal Arrangement on 'Secondary Recrystallization' in Metals."

(2) M. COOK and T. LL. RICHARDS : "Observations on the Annealing Characteristics of an Aluminium–Copper–Magnesium Alloy."

2.0 P.M. : Works and other visits for members and ladies.

6.0 P.M. : Autumn Lecture by Sir LAWRENCE BRAGG : "The Cavendish Laboratory."

Friday, 17th September

10.0 A.M. : All-day visits to works for members.

All-day visits to Peterborough and Ely Cathedrals for ladies.

Corrosion Exhibition—For the interest of those who will be in Cambridge to attend the Meeting, Dr. U. R. Evans has arranged an exhibition showing the past work of the Corrosion Research Section of Cambridge University. The exhibition will be open on Monday, 13th September, from 2.30 P.M., when Dr. Evans intends to be present, and on Tuesday, 14th September, 1948.

INSTITUTION OF METALLURGISTS

Refresher Course

A refresher course on "The Mechanical Working of Metals" is to be held at Ashorne Hill, near Leamington, from Friday, 1st October, to Sunday, 3rd October, 1948. Further details of the course will be given in next month's issue of the *Journal*.

NEWS OF SCIENCE AND INDUSTRY

The Woodall-Duckham Vertical Retort and Oven Construction Co. (1920), Ltd., announces the following changes in the management of the company, with effect from 1st July, 1948. :

Mr. F. B. RICHARDS, whilst retaining the Chairmanship of the company, has relinquished his position as a Joint Managing Director.

Mr. G. J. JACKSON will continue as a Joint Managing Director until his retirement from the Board on 31st December, 1948. Arrangements have been made to retain his services after that date in a part-time consultative capacity. Mr. Jackson will retain his seat on the Board of the parent company, Messrs. Woodall-Duckham (1920), Ltd.

Mr. J. S. JEFFREY and Mr. D. RIDER have been appointed Joint Managing Directors.

Mr. T. C. FINLAYSON is now Deputy Chairman.

The above changes are in conformity with the established policy of the company in regard to retirement and are designed to secure continuity in the management of the company's business.

MEMOIRS

By the death of Mr. **Harry Brearley** on 14th July, 1948, at the age of 77 years, the iron and steel industry has lost one of its outstanding personalities. He was known the world over as the discoverer of stainless steel and, as he humorously remarked on one occasion, as the man who invented knives that wouldn't cut !

He started life under what most people would regard as a big handicap. As he himself has put on record, he was born in a Sheffield slum district and lived there for several years during which time he received little or no education. His father was a crucible steel melter in the works of Messrs. Thos. Firth and Sons, Ltd., and young Harry spent many days during the early years of his life in and around the melting shop, so that he was, in truth, cradled in the steel industry. One of his first jobs was as laboratory boy in the chemical laboratory at the same works, where he came under the observation and influence of the then chief chemist, Mr. James Taylor, who encouraged and helped him to fit himself to become a steelworks chemist.

In 1901 he left Firths to start a new Laboratory at Messrs. Kayser Ellison & Co., Ltd., but returned to the company in 1904 to become chief chemist at their Riga Works of which he was appointed works manager in the following year. At the end of 1907 Mr. Brearley returned to Sheffield to design and equip the proposed Research Laboratory for Messrs. Thos. Firth and Sons, Ltd., and John Brown and Co., Ltd. It was during the period when he was Head of the Brown-Firth Research Laboratory that the discovery of stainless steel was made.

That he was an apt pupil during those early years with Mr. Taylor is evident to those who have read and used the book "The Analysis of Steel Works Materials" which, when little more than 30 years of age, he wrote jointly with Mr. Fred Ibbotson. Mr. Brearley repeatedly acknowledged his indebtedness to Mr. Taylor, whose memory he has perpetuated in the "James Taylor" prize which he endowed for biennial award by the Council of the Sheffield Metallurgical Association for the paper which, in its opinion, showed the greatest originality of conception or dealt most usefully with some metallurgical subject of current interest.

He resigned his position at the Brown-Firth Research Laboratory in 1915 and joined Messrs. Brown, Bayley's Steel Works, Ltd., as works manager, subsequently becoming Technical Director. He was a keen observer and had a lucid style of writing, features which are evident in his various books on technical subjects such as "The Heat Treatment of Tool Steels," "Case Hardening Steels," and "Ingots and Ingot Moulds." His later books are more in the nature of autobiography or reminiscences and are written in a very attractive style.

Throughout his life he was an individualist and professed to have little use for Technical or Research Committees, though he served on a few during the 1914–1918 War. He had little respect for tradition and often attacked it in his writings. In his last book, "Talks on Steelmaking," published in 1946 by the American Society for Metals, he attacked, in characteristically iconoclastic vein, a number of traditional views on certain aspects of steel metallurgy which he particularly disliked.

As a man he was kind and helpful to those who, he

thought, needed his help. His interest in his fellow men led him to inspire the formation of the Freshgate Trust Foundation, which would, as he put it, " help lame dogs over stiles."

In 1920 he was awarded the Bessemer Gold Medal by The Iron and Steel Institute, an honour which pleased him very much. He retired from active work at Brown, Bayley's Steel Works in 1925, though he retained his seat on the Board of Directors of that firm until his death. His years of retirement were spent mainly at Torquay with occasional visits to Sheffield, which became more and more infrequent especially during and since the war. He leaves a widow but no children, his only son dying about two years ago.—J. H. G. MONYPENNY

Cyrus Braby, eldest son of the founder and a chairman of the firm of Fredk. Braby and Co., Ltd., died on 20th May, 1948. He was 80 years old and had been a Member of The Iron and Steel Institute for 59 years. Born in 1867 at Sydenham Hill, he was educated at Rugby and joined Messrs. Braby and Co., Ltd., in 1885. He was made a Director of the company in 1890 and became manager of the London export office in 1901.

Mr. Braby's business life was spent mostly in the City, and although he was appointed Deputy Chairman in 1919 he remained at the export office until 1935, when, on the death of Mr. Walter Braby, he became Chairman. In 1942 Mr. Cyrus Braby thought that the affairs of the company should be directed by a younger man and he relinquished his post as Chairman in favour of his son, Mr. F. C. Braby, and himself reverted to the position of Deputy Chairman. This office he held until 1947, when advancing years and failing sight compelled him to retire from the Board.

The interests of Mr. Braby outside his business life were many. He was on the Board of Management of the British Home and Hospital for Incurables and of the Uckfield Cottage Hospital, and served on that of the Royal Metal Trades Pension and Benevolent Society from 1902 until his retirement in 1947. He was a Freeman of the City of London and a member of the Worshipful Company of Carpenters.

Henri Emile Faucillon died on 13th March, 1948. Born at Saulieu (Côte d'Or) in 1884, he was educated at l'Ecole Polytechnique and at l'Ecole d'Application des Ingénieurs d'Artillerie Navale. He became production manager at la Pyrotechnie de Saint-Nicolas and later works manager at la Fonderie Nationale de Ruelle and professor of the production of artillery at l'Ecole d'Application des Ingénieurs d'Artillerie Navale.

In 1923 M. Faucillon was attached to the inter-allied control commission for the mines and works of the Ruhr. In 1925 he was appointed chief engineer of the metallurgical department at the Creusot Works of the Schneider Company, and in 1930 took charge of the commercial as well as the technical aspects of the metallurgical department. The mining and metallurgical departments were later combined under his control.

James H. Herron, consulting engineer and President of the James H. Herron Company, Cleveland, Ohio, died on 29th March, 1948, in Fort Lauderdale, Florida.

James Herron was a graduate of the University of Michigan and was awarded the degree of Doctor of Engineering of the Case Institute of Technology in 1943. Before founding the James H. Herron Company in 1909, he was Vice-President of the Bury Compressor Company, of Erie, Pennsylvania, Detroit manager of the Motch and Merryweather Company, and chief engineer and works manager of the Detroit Steel Products Company.

Mr. Herron's greatest activity was found in the engineering societies of the United States. He had been National President of the American Society of Mechanical Engineers, President of the Cleveland Engineering Society, and of the Cleveland Section of the American Society of Civil Engineers. He took part recently in the formation of the Cleveland Technical Societies Council. During the recent war he served on the President's National Fuel Efficiency Programme. Mr. Herron had been a Member of The Iron and Steel Institute since 1912.

Joseph Hutchinson Harrison, of Messrs. Jos. H. Harrison and Son, Consulting Engineers, Middlesbrough, died on 6th April, 1948, at the age of 88. He had been a Member of The Iron and Steel Institute since 1894, and was made a Life Member in 1948. After attending the late John Calvert's School, he served an engineering apprenticeship from 1874 to 1880 with Messrs. Bolckow, Vaughan and Co., Ltd., at the same time furthering his technical knowledge at evening classes. From 1880 to 1882 he was assistant to the resident engineer on the conversion to a Bessemer steel rail plant of the Erimus Puddled Iron Works at South Stockton, under the direction of Samuel Godfrey. For the next seven years, as a draughtsman with Bolckow, Vaughan and Co., Ltd., he was concerned with the redesigning and modernization of their blast-furnaces and with the installation of two salt-making plants, under E. Windsor Richards. In 1888 he was appointed head draughtsman. Resigning this position in 1889, he became assistant to the late Bernard Dawson and was engaged in the design of much iron and steel plant, notably for the Earl of Dudley's Round Oak Works.

In 1892 he took over the consulting engineering practice of the late Richard Howson and continued in this work until his death. During this long period he carried out a great deal of remodelling work to various blast-furnaces, in addition to the design of new plants. He twice visited the Urals district to report upon charcoal-using blast-furnaces. The design of the first commercially successful blast-furnace in Australia was originated by him, and he also supervised the production and despatch of all necessary special machinery and material.

In the course of his work he visited many iron and steel plants in Belgium, France, Germany, and Luxembourg.

With the late Dr. Stead, Mr. Harrison worked hard for the establishment in Middlesbrough of what has since become the Cleveland Scientific and Technical Institution. He was a member of the Institution of Civil Engineers, of the Institution of Mechanical Engineers, and a Past-President of the Cleveland Institution of Engineers.

John Henry Moysey died on 19th May, 1948. He had been a Member of The Iron and Steel Institute for 45 years. Educated at King's College, London, Mr. Moysey served his apprenticeship with Earle's Shipbuilding and Engineering Co., Ltd. Subsequently he was engaged as a draughtsman with the Greenock Foundry Co., Ltd., and later with Messrs. MacIlwaine and McColl, Ltd., of Belfast. In 1893 he became a partner in the General Engineering Works, at Bow, London, after which he held positions as draughtsman with Messrs. Easton Anderson, Ltd., of Erith, and with Messrs. Davy Bros., Ltd., of Sheffield.

In 1898 Mr. Moysey was appointed leading draughtsman to the North-East Steel Co., Ltd., Middlesbrough. From 1902 to 1906 he was assistant engineer with the Cargo Fleet Iron Co., Ltd., where he was in charge of the erection of the rolling mills, soaking pits, and other plant.

He then transferred to the Central Zinc Co., Ltd., Seaton Carew, being appointed works engineer from the commencement of the works. In 1915, at the request of Mr. H. H. Ridge, he left the Central Zinc Works to

put down a large oleum plant at Manchester, and in 1918 was appointed to the head office in London as engineer for designing chemical plant.

Sir **Henry Robertson,** of Pale, Llandderfel, died on 20th May, 1948, aged 86. He was Chairman of the Brymbo Steel Co., Ltd., of the Broughton and Plas Power Coal Co., Ltd., and of the Minera Lime Co., Ltd.

The son of Henry Robertson, M.P., designer of the Dee Viaduct at Cafn, and founder of the steel industry at Brymbo, Sir Henry Robertson was born in 1862 and educated at Eton and at Jesus College, Cambridge, where he took his B.A. degree in science in 1884. On completion of his academic course at Cambridge he joined his father at Pale to assist him in his many business activities.

At the age of 28, a year after the death of his father, he was knighted by Queen Victoria, partly as the result of a visit to Pale by the Queen and partly in recognition of the great services rendered by his father in the development of North Wales.

Sir Henry's business activities, apart from his interest in the Beyer Peacock Company, locomotive builders, were mainly centred around the Brymbo Steel Company's undertakings. His industrial enterprises continued to expand until the depression of the 1930's. The Brymbo Steel Co., Ltd., went into liquidation in 1930, but by Sir Henry's unrelenting efforts a new company was formed and the steelworks revived and played a prominent part in the recent war. For over fifty years he was on the Board of the Great Western Railway Company, and always maintained the greatest interest in the company and its staff.

Outside the business world his interests were numerous and were always carried on with the utmost enthusiasm.

Sir Henry joined The Iron and Steel Institute in 1894 and was a contributor to the *Journal*.

Sir **William John Talbot,** Chairman of the Talbot-Stead Tube Co., Ltd., Walsall, and of the Chesterfield Tube Co., Ltd., Chesterfield, died on 10th December, 1947, aged seventy-five. Sir William received his engineering training with Messrs. Bellis and Morcom, Ltd., of Birmingham, later becoming works manager at the Perfecta Tube Co., Ltd., Birmingham, and afterwards at Messrs. John Russell and Co., Ltd., Walsall. The Talbot-Stead Tube Co., Ltd., was founded by him in 1906. Sir William received the honour of a knighthood in 1935. A Freeman of the City of London, he was a Past-President of the Walsall Chamber of Commerce, and a member of the Executive Council of the Association of British Chambers of Commerce. He was appointed High Sheriff of Staffordshire in 1947.

Sir William, who was also a member of the Institute of Metals, joined The Iron and Steel Institute in 1905.

Sydney Smith, Managing Director of the Wellman Smith Owen Engineering Corporation, Ltd., died on 30th May, 1948, at Orpington, Kent. Mr. Smith, who had been associated with the Corporation since 1922, succeeded his brother, the late Mr. James Foster Smith, as managing director in February 1947.

Born at Hitchin, in Hertfordshire, and educated at Harpenden, Mr. Smith was apprenticed to Messrs. Robey and Co., Ltd., of Lincoln, in 1898, after which he served for one year in the drawing office. He also furthered his technical training at the Lincoln Technical College.

In 1906 he joined the crane department of Messrs. Babcock and Wilcox, Ltd., in London, and remained with that company until 1908. In that year he was appointed leading draughtsman with Messrs. Wellman Leaver and Head, and took part in outside erection work. Mr. Smith then went to Canada for three years, where he gained new experience with the Jeffrey Manufacturing Company, of Montreal, with Mussens, Ltd., of Montreal, and with the Jenckes Machine Company, of Sherbrooke, Quebec Province.

On his return to Great Britain in 1914 he was appointed engineer to the Whitehead Iron and Steel Co., Ltd., for its proposed extensions, and was later made engineer-in-charge of the Briton Ferry Steel Works ; this position he continued to hold until he joined the Wellman Smith Owen Engineering Corporation in 1922. For a short time he was in charge of the section dealing with pulverized-fuel machinery and was then made responsible for the management and development of the seamless-steel-tube machinery section. Before succeeding his brother as managing director in 1947 he acted as chief engineer.

Mr. Smith was a member of the Institution of Mechanical Engineers and joined The Iron and Steel Institute in 1926.

DIARY

26th Aug.–11th Sept.—1948 Machine-Tool and Engineering Exhibition—Olympia, London.

14th–17th Sept.—INSTITUTE OF METALS—Autumn Meeting at Cambridge.

15th–19th Sept.—International Foundry Congress—Prague. A post-congress tour will take place from 20th to 26th September, 1948.

21st–23rd Sept.—INSTITUTE OF PETROLEUM AND INSTITUTE OF FUEL—Joint conference on "*Modern Applications of Liquid Fuels*"—Birmingham University.

21st – 28th Sept.—International Rheological Congress organized by a Dutch Committee—Sibeveningen, near The Hague.

23rd – 25th Sept.—INSTITUTION OF PRODUCTION ENGINEERS—National Convention at Bournemouth.

TRANSLATION SERVICE

(The previous announcement was made in the July, 1948, issue of the *Journal*, p. 320.)

TRANSLATIONS AVAILABLE

No. 350 (German). W. OELSEN and H. WIEMER : "Immiscibility Phenomena in Ferrous-Oxide/Sodium-Phosphate Slags." (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1942, vol. 24, No. 13, pp. 167–210).

No. 351 (Swedish). S. MÖRTSELL : "Rationalisation in Swedish Iron-Ore Dressing." (*Jernkontorets Annaler*, 1946, vol. 130, No. 9, pp. 369–460).

PAPER ACCEPTED FOR TRANSLATION SINCE THE LAST ANNOUNCEMENT

(Swedish). G. WALLQUIST : "Graphical Roll Calibration." (*Jernkontorets Annaler*, 1948, vol. 132, No. 2, pp. 27–41.

TRANSLATIONS PREPARED AT MEMBERS' REQUEST—Members requiring translations of foreign papers are invited to communicate with the Secretary, who will ascertain whether the translations can be prepared for inclusion in the Series.

Increase of Charges

Members are reminded that, as from 1st July, 1948, the price of translations has been increased to £1 for one copy of any translation in the Series, and 10*s.* for each additional copy of the same translation. Requests should be accompanied by a remittance.

Translations in the Series are not available on loan from the Joint Library.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

The Sequence and Structure of the Southern Portion of the East Crop of the South Wales Coalfield. L. R. Moore. (Quarterly Journal of the Geological Society of London, 1948, vol. 103, Part 4, pp. 261–300).

Iron and Asbestos in the North of Western Australia. C. M. Harris. (Mining Magazine, 1948, vol. 78, Apr., pp. 201–208). Details are given of the Yampi iron deposits, and the prospects of their exploitation, as a result of the Iron and Steel Industry Act of 1947, are discussed. —M. A. V.

The Microstructure of Titaniferous Iron Ore at Otanmäki. O. Vaasjoki. (Comptes Rendus de la Société Géologique de Finlande No. 20 : Bulletin de la Commission Géologique de Finlande, 1947, No. 140, pp. 107–114 : Chemical Abstracts, 1948, vol. 42, May 10, col. 2896). Complete analyses are given of the ore and of the separated magnetite and ilmenite. Vanadium and chromium are higher in the magnetite, magnesium and manganese in the ilmenite. They contain respectively, V_2O_3 0·68%, 0·18%; Cr_2O_3 0·20%, trace; MgO 1·08%, 3·42%; MnO 0·03%, 0·24%. Microscopic study indicated that the ore underwent a period of metamorphism after its formation.

Coal in Europe. J. V. Mickwitz. (Angewandte Chemie, 1948, vol. 20, Section B, Jan.–Feb., pp. 33–42). The coal economy of the different countries of Europe is discussed with data on production.—R. A. R.

Refractory Clay Deposits in Brittany. (Génie Civil, 1948, vol. 125, May 15, p. 196). The clay deposit at Saint-Aubin-des-Chateaux in Britanny is described. It yields a clay of high alumina content suitable for the manufacture of refractories.—R. F. F.

Moroccan Cobalt Deposits at Bou-Azzer. (Echo des Mines, 1948, May, pp. 72–73). The exploitation of the Bou-Azzer cobalt deposits is briefly described.—R. F. F.

The Mbamba Bay Coalfield, Tanganyika Territory. D. A. Harkin. (Mining Magazine, 1948, vol. 78, May, pp. 265–272).

FUEL—PREPARATION, PROPERTIES, AND USES

Mechanisms of Combustion and Their Relation to Oil Burner Design. H. R. Heiple and W. A. Sullivan. (Transactions of the American Society of Mechanical Engineers, 1948, vol. 70, May, pp. 343–350). A series of experiments was carried out, mainly between 400° and 1100° F., with the object of elucidating the mechanism of oxidation of hydrocarbons. Hydrocarbons in the fuel-oil range oxidize in air below the ignition point ; they undergo cracking when heated, either alone or mixed with air. The mechanism of oxidation in the flame probably differs from that at lower temperatures. The principles of hydrocarbon oxidation are applied to the design of vapourizing and atomizing burners, and recommendations are made. In the vapourizing burner recommended, fuel is thrown centrifugally on to a hot steel or ceramic surface. A regulated quantity of air from a fan is mixed with the vapour, which burns above a series of grills, or flame retainers. With atomizing burners, it is recommended that some of the combustion air be introduced into the oil mist before passage into the flame front, and the remainder of the combustion air either introduced by the burner fan, or drawn by the flame itself from the surrounding atmosphere. There should be no possibility of infringement on combustion-chamber walls or portions of the burner.—M. A. V.

Photographic Techniques in Combustion Research. L. Beral and W. T. Cooper. (Fuel, 1948, vol. 27, Jan.–Apr., pp. 10–18). (*See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 289).

Research in the Sphere of Steam Generation. P. Profos. (Schweizer Archiv, 1948, vol. 14, Feb., pp. 33–38). The practical and theoretical conditions which govern progress in the design of boilers are discussed.—R. A. R.

Data and Fuel Saving by the Application of the Underfeed Stoker to Kilns. H. Torkington. (Symposium on Mechanical Firing : Transactions of the British Ceramic

Society, 1948, vol. 47, May, pp. 177–183). The construction and operation of intermittent kilns, firing various products (including silica bricks), fitted with underfeed stokers, are described, and some fuel consumption data given.—M. A. V.

Recuperation in Relation to Furnaces. C. H. Williams. (Ministry of Fuel and Power, Fuel Efficiency Committee Conference on "Fuel and the Future," London, Oct., 1946, vol. 2, pp. 122–125). Data are given on savings achieved by recuperating combustion air in a coke-oven-gas-fired furnace, and the design of metallic and refractory recuperators is discussed.—M. A. V.

The Influence of Mechanisation on Coal Preparation. H. G. Hague. (Journal of the Institute of Fuel, 1948, vol. 21, June, pp. 236–241). *See* Journ. I. and S.I. 1948, vol. 158, Apr., p. 527.

Maintenance of a Coal Cleaning Plant. R. M. Hunter. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2379 : Coal Technology, 1948, vol. 3, May).

Flotation of Bituminous Coal. R. E. Zimmerman. (American Institute of Mining and Metallurgical Engineers ; Technical Publication No. 2397 : Coal Technology, 1948, vol. 3, May). Laboratory experiments carried out by the Pittsburgh Coal Co. have demonstrated the practicability of cleaning bituminous fine coal by flotation. Control of *p*H is important ; a range of 7·0 to 7·5 gave the highest recovery. Greater acidity improves ash removal, but leads to a higher iron sulphide content. A range of 8·0 to 8·5 is recommended in practice. A frothing agent should be chosen which produces a brittle froth, and the use of kerosene, fuel oil, or crude petroleum as a collector is satisfactory. Bulk oil flotation was particularly effective in removing clay, especially when dealing with extreme fines ; but air picks up all carbonaceous material, and, moreover, is costly.—M. A. V.

A History of Pulverised Fuel Firing. (Engineering and Boiler House Review, 1948, vol. 63, Jan., pp. 13–17 ; Feb., pp. 34–39 ; Mar., pp. 68–72, 85). Descriptions are given of some of the first methods of firing boilers and furnaces with pulverized coal.—R. A. R.

Determination of Production Costs of Low-Ash Preparations from Coal. W. Banse. (Bergbau-Archiv, 1947, vol. 4, pp. 55–83 : British Abstracts, 1948, Section B1, Feb., col. 62). A method of calculating prices for cleaned coal products, based on the ash content and aimed at encouraging the up-grading of suitable coals for special purposes or as raw materials for industrial uses, is proposed. Such products include specially washed low-ash (4–8%) coal, and materials separated by additional treatment from selected seams, such as low-ash (1·5–3%) coking coal for special metallurgical use, high-volatile low-ash (4%) coal for hydrogenation, coal for making semi-coke for mobile producers (ash 4%, volatile matter 30–35%), and anthracite for active carbon and electrodes (ash 0·5–2%).

A Consideration of the Bulletins of the Fuel Efficiency Committee of the Coking Industry from the Plant Constructor's Viewpoint. D. T. Barritt and T. C. Finlayson. (Ministry of Fuel and Power, Fuel Efficiency Committee Conference on "Fuel and the Future," London, Oct., 1946, vol. 2, pp. 225–236). The subjects discussed are oven design, constancy of operating conditions, heat losses, collecting-main regulation, control instruments, technical supervision, plant maintenance, and steam raising.—M. A. V.

A Modified Method for Calculating the Fuel Efficiency of a Coke Oven Battery. F. H. Metcalf and G. A. Hebden. (Ministry of Fuel and Power, Fuel Efficiency Committee Conference on "Fuel and the Future," London, Oct., 1946, vol. 2, pp. 211–219). Equations are derived for the fuel efficiency of coke-oven batteries fired with coke, blast-furnace or producer gas, and nomograms constructed for their solution.—M. A. V.

Coking of Coal with Chrome Ore to Obtain Chrome Coke for the Production of Pig Iron Rich in Chrome in Blast Furnace. N. P. Tschischewsky and D. M. Chernyshev. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1946, vol. 53, pp. 237–238 : British Abstracts, 1948, Section B1, Feb., col. 79). The coke obtained by adding about 20% of chrome ore to the production charge is very hard, strong, of high density, and similar to good metallurgical coke.

Tar Seam, Plastic Zone, and Coking Velocity. Terbeck. (Glückauf, 1948, vol. 81/84, May 8, pp. 327–330). Examined from the kinetic point of view the coking process consists of two mechanisms, one progressive and the other stationary. In the former the transformation from coal into coke moves from the walls to the centre of the charge, whilst the latter consists of the transformation of the individual stationary grains. Formulæ and curves are presented for the velocities of these transformations in relation to time, temperature, and gas pressure in the oven.—R. A. R.

The Gasification of South Wales Coals. D. Hicks. (Ministry of Fuel and Power, Fuel Efficiency Committee Conference on "Fuel and the Future," London, Oct., 1946, vol. 2, pp. 136–139). Modern practice in the gasification of South Wales anthracites and bituminous coals in producers is outlined. The importance of continuous close supervision of producer operation is emphasized.—M. A. V.

Gas Producers in the Iron and Steel Industry. F. A. Gray. (Ministry of Fuel and Power, Fuel Efficiency Committee Conference on "Fuel and the Future," London, Oct., 1946, vol. 2, pp. 139–140). The requirements of efficient producer practice are discussed. It is suggested that research is needed on preheating and oxygen-enriching the blast, and on desulphurizing the raw hot gas.—M. A. V.

Combustion with Oxygen and Oxygen-Enriched Air. Part I—Thermodynamic Data and Their Implications for High Temperature Heating Processes. H. R. Fehling. (Journal of the Institute of Fuel, 1948, vol. 21, June, pp. 221–235, 241). *See* Journ. I. and S.I., 1948, vol. 159, May, p. 85.

The Electric Infra-Red Process. J. C. Lowson. (Ministry of Fuel and Power, Fuel Efficiency Committee, Conference on "Fuel and the Future," London, Oct., 1946, vol. 1, pp. 246–254). *See* Journ. I. and S.I., 1947, vol. 156, May, p. 134.

Town's Gas for Drying by Radiant Heat. R. F. Hayman. (Ministry of Fuel and Power, Fuel Efficiency Committee Conference on "Fuel and the Future," London, Oct., 1946, vol. 1, pp. 254–262). *See* Journ. I. and S.I., 1947, vol. 155, Mar., p. 455.

The Handling of Oil Fuel. (Engineering and Boiler House Review, 1948, vol. 63, May, pp. 143–144). Fuel oils are classified into Pool Gas Oil, Pool Fuel Oil, and various grades of coal-tar fuel, depending on the viscosity. The temperatures necessary for (*a*) efficient pumping and (*b*) atomization, are tabulated and details given of suitable storage arrangements. It is emphasized that before changing over from coal-tar derivatives to crude oil derivatives, the system must be thoroughly cleansed. —M. A. V.

A Comparison of Coal and Oil Firing. A. C. Dunningham. (Fuel, 1948, vol. 27, Jan.–Apr., pp. 4–9). A theoretical study of combustion conditions in coal- and oil-fired boiler furnaces shows that oil-firing only offers a slight increase in efficiency. This is borne out by practical experience, and at present price levels,

steam costs are 50% higher with oil-firing. Oil may, however, be used economically in small amounts to assist the combustion of low-grade fuels.—M. A. V.

REFRACTORY MATERIALS

The CaO-MgO-Cr_2O_3 Ternary System. Part I—A Partial Investigation of the CaO-Cr_2O_3 System. F. Ford and W. J. Rees. (Transactions of the British Ceramic Society, 1948, vol. 47, June, pp. 207–231). On heating mixtures of lime and chromic oxide in air, tetragonal calcium chromate is formed; in the presence of excess lime, this loses oxygen and an acid-insoluble compound, $9CaO.4CrO_3.Cr_2O_3$ is produced. This latter melts congruently at 1228° C., and the eutectic between it and lime melts at 1174° C. and has the approximate composition CaO 54% and Cr_2O_3 46%. Calcium chromate, alone or in presence of excess Cr_2O_3 dissociates at 1022° C. with the loss of oxygen and the formation of a liquid and the true binary compound $CaO.Cr_2O_3$, calcium chromite; below 1022° C. this oxidizes slowly to form the chromate and chromic oxide.—J. P. S.

Details of the Quartz Transformation in Silica Bricks. P. T. Holmquist. (Ingeniörsvetenskapsakademiens Handlingar, 1947, No. 192: Acta Polytechnica, 1947, No. 5). *See* Journ. I. and S.I., 1947, vol. 156, May, p. 129.

Refractories. H. M. Kraner. (Ceramic Age, 1947, vol. 50, p. 45: British Ceramic Abstracts, 1948, Jan.–Feb., p. 24A). Studies of the relations between chemical and mineralogical composition led to the realization that methods of forming affected physical properties, from which have sprung de-airing, the S.u.G. process, chemical bonding of graded basic refractories, and fusion casting. In the past twenty-five years considerable advances have been made with silicon carbide and sillimanite refractories. The resistance of the latter to thermal shock and alkali attack stimulated its use for glass-tank refractories, culminating in the production of mullite refractories by melting and casting. Zircon and zirconia have also been included in these refractories. Fired zirconia bodies can be prevented from undergoing dusting due to polymorphic volume change on cooling by stabilizing additions. Forsterite refractories from olivine and magnesia have been developed. Reduction of porosity in blast-furnace refractories from 24% to 16–18% has been achieved. Super-duty bricks were developed in 1930, replacement of bauxite by diaspore in high-alumina bricks alleviated the shrinkage problem, and silica bricks were dry-pressed in 1929. "Jersey clay" bricks have been found to withstand heavy loads at high temperatures. Clay insulating bricks with a wide range of refractoriness have been developed, and carbon is now regarded as the logical material for blast-furnace hearths. Calcination and grading of dead-burned magnesites have been practised for producing ramming mixes since 1936, and cracks developed in rammed hearths are now sealed with slag-magnesite mixtures. Sized aggregate, chemically bonded and pressed, is used in a wide range of basic compositions to produce unfired magnesite and chrome refractories. Improved chrome-magnesite compositions have led to a more extensive use of basic refractories in "all-basic" furnaces.

Refractory Developments Keep Pace with Industrial Progress. (Brick and Clay Record, 1947, vol. 110, No. 1, pp. 56–62: American Ceramic Abstracts, 1948, Apr., pp. 74–75). A survey of developments marking recent progress in the refractories industries includes: (1) The use of rotary kilns to precalcine diaspore and eliminate objectionable shrinkage characteristics of that material; (2) pebble heaters employing a moving column of refractory pebbles as the heat exchanger; (3) installation of all-basic ends in open-hearths and the advent of experimental all-basic construction in open hearths; (4) control of alumina and alkali in silica brick to produce a super-duty refractory with an increase in refractoriness of 100° F., resulting in 10–30% increased open-hearth roof life; (5) development of basic ramming mixes for electric and conventional open-hearths; (6) development of universal cupola blocks; (7) development of zircon refractories for aluminium melting furnaces, a 99% alumina refractory, a recrystallized mullite refractory with a crystalline bond, and a light-weight mullite refractory (500 lb/100 cu in).

Recent Developments in Refractories. H. M. Kraner. (Iron and Steel Engineer, 1948, vol. 25, Apr., pp. 59–64). The trend in blast-furnace linings is towards hard-fuel and "super-duty" refractories for the stack and towards carbon for the hearth, although the last has not been accepted to the extent of the other two. In open-hearth bottoms, construction leans towards the use of magnesite brick with a layer of magnesite sintered on top. For the roofs, silica brick in which the alumina content is kept as low as possible is still the most valuable.—J. P. S.

The Selection and Use of Hot-Face Insulating Bricks. L. R. Barrett. (Ministry of Fuel and Power, Fuel Efficiency Committee Conference on "Fuel and the Future," London, Oct., 1946, vol. 2, pp. 93–98). Data are given on the heat losses from parts of open-hearth furnaces, with hot-face temperatures above and below 1400° C., on the heat transmission through firebrick walls and on the properties of British hot-face insulating bricks.—M. A. V.

The Selection of Refractory Materials in Relation to Fuel Economy. G. R. Rigby. (Ministry of Fuel and Power, Fuel Efficiency Committee, Conference on "Fuel and the Future," London, Oct., 1946, vol. 2, pp. 99–109). *See* Journ. I. and S.I., 1947, vol. 155, Jan., p. 146.

Bottom Refractory Discloses Freedom from Hydration. (Blast Furnace and Steel Plant, 1948, vol. 36, May, p. 562). Examination of the bottom of five furnaces erected in 1942, of which three were never used and two had made only 186 and 106 heats respectively, showed that the refractory employed ("Ramset") had satisfactorily resisted slaking.—J. P. S.

The Open-hearth Furnace—Making the Most of Silica Roofs. J. H. Chesters. (Iron Age, 1948, vol. 161, Apr. 29, pp. 72–76; May 6, pp. 86–93). The author advises the use of silica brick made from raw materials of higher than the conventional purity, especially with regard to alkali and alumina content, finished to a higher bulk density, and consistently fired to a given specific gravity. Roofs made of such brick should be heated at a controlled rate, and maintained by design and operation at a temperature approaching but not exceeding the maximum safe temperature.—J. P. S.

Acid Refractory Mortar for Laying Silica Firebrick in High Temperature Furnaces. S. S. Bermant. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1946, vol. 54, pp. 803–804: British Abstracts, 1948, Section B1, col. 75). The use of marshallite as an acid refractory mortar has been investigated. The most satisfactory mortar had the composition: ground quartzite 85%, marshallite 15%; sulphite-pulp waste-water (sp.gr. 1·26) 3% should be added. The mortar has been tested in an open-hearth furnace, and shows the following characteristics: absence of flowing of fused mortar from the joints of the arch, sintering of the mortar with the SiO_2 bricks resulting in the formation of a monolithic structure, less permeability of the arch to gases as compared with the arch when laid dry, and increase in time of furnace life.

Oxygen Firing Furnaces of Industry Is Placing New Demand on Refractories. (Brick and Clay Record, 1948, vol. 112, No. 1, p. 56 : American Ceramic Abstracts, 1948, Apr. 1, p. 74). During 1947 oxygen was tried both for melting steel and for purging it of carbon content. It reduced melting time up to 30%, saved 20% in fuel, and gave fast, accurate results in purging, but it also raised a number of problems, including the unanswered question of the effect on refractories of the higher oxygen temperatures and the violent action (in which gobs of molten steel are thrown to the roof). The glass industry is divided on the possibility of using oxygen for melting ; both groups believe the melting area can be smaller, but one group advocates larger checkers, while the other group believes that none will be required. Cheap oxygen will be of interest to ceramists, and, predicated on the use of prefired materials, may prove a new tool.

Magnesite Nozzles for Steel Ladles. G. M. Tazitdinov. (Ogneupory, 1946, vol. 11, No. 11–12, p. 32 [in Russian] : British Ceramic Abstracts, 1948, Jan.–Feb., p. 26A). The preparation of the material for shaping by hand and in presses is described, and an account is given of experiments designed to improve the quality of the products. The addition of fluxes produced stronger nozzles, but led to deformation and cracking in the kiln. A considerable increase in strength was secured by working the soured batch in a tempering pan for periods up to 20 min. Maximum strength together with a maximum kiln loss were obtained with a mixture containing 70 parts of magnesite calcined in a rotary kiln with 30 parts of magnesite from a shaft kiln. Chrome-magnesite nozzles were found to be less strong than magnesite, but were less prone to freezing in the ladle.

Production of Steel-Ladle Stoppers. E. A. Kogon. (Ogneupory, 1946, vol. 11, No. 9–10, p. 3 [in Russian] : British Ceramic Abstracts, 1948, Jan.–Feb., p. 26A). An account is given of various ceramic mixtures. Graphite-fireclay, clay-bonded andalusite, and fireclay mixtures are described.

Use of Flint Clay in Casting Pit Refractories. I. P. Kvitchenko and A. I. Udovichenko. (Ogneupory, 1946, vol. 11, No. 11–12, p. 39 [In Russian] : British Ceramic Abstracts, 1948, Jan.–Feb., p. 26A). A note is given on laboratory trials in which an Armenian flint clay was used as a substitute for grog in receiver brick and sleeve batches.

Roof Life in Electric Arc Steel Furnaces. M. S. Kamenichnyi and M. P. Nazarov. (Ogneupory, 1946, vol. 11, No. 11–12, p. 16 [In Russian] : British Ceramic Abstracts, 1948, Jan.–Feb., p. 26A). The roof lives of electric furnaces at four steelworks are examined and compared in the light of the composition and properties of the roof bricks, furnace design, operating conditions, and constructional technique. It appears that structural features such as the bath-to-roof distance and operating conditions, in particular the duration of the melt, have more influence on the roof life than factors associated with the properties of the roof bricks.

Design and Performance of a Refractory Recuperator. E. S. Smith. (Iron and Steel Engineer, 1948, vol. 25, Apr., pp. 106–112). Vertical-tube refractory recuperators have been applied to soaking pits and slab heating furnaces. The high heat-storage capacity of refractory materials makes this type of recuperator a very useful stabilizer of air preheat-temperature. It is considered that the application of the same principles to open-hearth firing would have a great effect on production costs, fuel consumption, and maintenance charges.—J. P. S.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

The Effect of Operating Conditions on Type of Reduction and Carbon Rates in the Blast Furnace. J. Taylor. (West of Scotland Iron and Steel Institute, 1948, Preprint). The over-all thermal and reduction requirements in blast-furnaces are computed in an endeavour to determine quantitatively the effect of various factors, *e.g.*, blast temperatures, slag bulk, and heat losses, on the carbon consumption per ton of pig iron.—M. A. V.

Investigation of the Distribution of Sulphur and Manganese between Slag and Iron in the Production of Foundry Pig Iron. E. Braaten. (Tidsskrift for Kjemi, Bergvesen og Metallurgi, 1948, vol. 8, No. 2, pp. 19–22). [In Norwegian.]

Experimental Furnaces of the British Iron and Steel Research Association ("B.I.S.R.A."). M. Davies. (British Science News, 1948, vol. 1, No. 8, pp. 2–5). Illustrated descriptions are given of the B.I.S.R.A. experimental blast-furnace (12 ft. 4 in. high). and open-hearth furnace (18 ft long over-all) at Stoke-on-Trent. The scope of the experiments is outlined. Open-hearth tests indicate that, with all other conditions kept constant, better heat transfer is obtained with high furnace pressures. There is evidence that two or more small gas ports would be better than one of equivalent area. The air port should surround the gas inlet as far as possible.—R. A. R.

The Application of Oxygen in the Operation of the Blast Furnace. D. D. Howat. (Blast Furnace and Steel Plant, 1948, vol. 36, May, pp. 533–538, 592, 602). The author outlines the history of the use of oxygen in the blast-furnace, discusses several of the published studies and concludes that the application of oxygen does improve fuel consumption and output of iron, and lowers top-gas temperatures. The limit for practical and continuous operation appears to be 25–30% of oxygen by volume, and extensive application will involve considerable alteration in design and operation.—J. P. S.

An Examination of Blast-Furnace Scaffolds and Scaffold-Forming Materials. J. H. Chesters, I. M. D. Halliday, and J. Mackenzie. (Journal of The Iron and Steel Institute, 1948, vol. 159, May, pp. 23–36).

Progress in High Pressure Operations of Blast Furnaces. B. S. Old, E. L. Pepper, and E. R. Poor. (Iron and Steel Engineer, 1948, vol. 25, May, pp. 37–47). Descriptions are given of the engineering alterations which are necessary to convert a blast-furnace and ancillary plant of conventional design for operation at high top pressure. Apart from the additions or changes in the blowing plant, such alterations are not expensive. The advantages of the process, already reported in the literature, are discussed.—R. A. R.

Manufacture of Pig-Iron from Ore Fines and Non-Coking Coals. P. Lameck. (Iron and Coal Trades Review, 1948, vol. 156, June, 4, pp. 1173–1177). The production of pig iron by a briquetting process invented by L. Weber in co-operation with the Klöckner-Humboldt-Deutz Company, Cologne, is described. The ore is mixed with an amount of coal sufficient to smelt it and, after adding a binder, the mixture is briquetted by a roller press into ovoids which are subjected to low-temperature carbonization in a retort at 550–600° C. ; they are then smelted in a low-shaft furnace. A flow sheet for the process and some results obtained in trials are presented.—R. A. R.

How a Steel Mill Prepares Blast-Furnace Gas for Fuel. W. M. Cline. (Power, 1947, vol. 91, Nov., pp. 72–73 : Fuel Abstracts, 1948, vol. 3, Apr., p. 88). The author gives a description of blast-furnace operation, indicating

the ratio of ore, coke, limestone, and air fed to the furnace, and the composition of the resulting gases. Storage and distribution of the gases are considered.

Power Requirements for Charging Modern Blast Furnaces. C. C. Downie. (Power Transmission, 1947, vol. 16, Oct. 15, pp. 1049–1052 : [Abstract]. PERA Bulletin, 1948, vol. 1, Jan., p. 205). A brief description of six modern plants showing tonnages and speeds of handling is followed by a general survey of control and hoisting gear arrangements for one or two-man control of semi-automatic plants.

The Blast-Furnace As Gas Producer. K. Guthmann. (Stahl und Eisen, 1948, vol. 68, May 20, pp. 186–192). The literature on the operation of the blast-furnace as a gas producer, using a slag burden and a high coke rate, is reviewed and German experience during the 1939–45 war is presented and discussed.—R. A. R.

PRODUCTION OF STEEL

Manufacture, Testing and Inspection of Alloy Steels. H. Oakden. (Journal of the South African Institution of Engineers, 1948, vol. 46, Feb., pp. 151–168). The increased use of British Standard and " En " specifications for steel is noted, and the manufacture, fabrication, and testing of steels to conform with these specifications described.—M. A. V.

Marshall Aid and the European Steel Industry. W. Salewski. (Stahl und Eisen, 1948, vol. 68, Jan. 1, pp. 15–19 : Iron and Coal Trades Review, 1948, vol. 156, May 21, pp. 1077–1078). Section V of the Report submitted by the Committee of European Economic Co-operation on Sept. 22, 1947 deals with the needs of, and plans for, the iron and steel industries of Europe. The chief points and implications of these plans are discussed. —R. A. R.

Aerodynamics in Relation to Furnaces. A. H. Leckie. (Ministry of Fuel and Power, Fuel Efficiency Committee Conference on " Fuel and the Future," London, Oct., 1946, vol. 2, pp. 112–116). Problems of importance in furnace design are (*a*) the introduction of sufficient gas and air into the furnace, and the removal of combustion products together with infiltrated air, and (*b*) the ensuring of efficient combustion and heat transfer. The work of various investigators, including that of the British Iron and Steel Research Association, is reviewed, with particular reference to steel furnaces. —M. A. V.

The Development of the Open-Hearth Furnace. Sir Andrew McCance. (Presidential Address : Journal of The Iron and Steel Institute, 1948, vol. 159, May, pp. 1–10).

The Possibilities of Using Liquid Fuel in Iron and Steel Works. W. Karlsson. (Iron and Steel Institute, 1948, Translation Series, No. 345). This is an English translation of a paper which appeared in Värmländska Bergsmannaföreningens Annaler, 1946, pp. 47–94 (*See* Journ. I. and S.I., 1948, vol. 158, Feb., p. 266). R. A. R.

Multiple Correlation Applied to Steel Plant Problems. W. T. Rogers. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 935–953). *See* Journ. I. and S.I., 1948, vol. 158, Mar., p. 396.

An Application of Multiple Correlation to a Problem in Basic Open Hearth Operating Rates. R. H. Ede. (Industrial Heating, 1948, vol. 15, Mar., pp. 442, 444, 446, 448). In an attempt to throw light on the factors influencing operating rates, a statistical analysis was made of data collected on 357 heats of a basic open-hearth furnace. It is concluded that : (*a*) Large differences between melt carbons and tap carbons should be avoided ; (*b*) large lime additions should be avoided ; (*c*) the conclusions noted in (*a*) and (*b*) are particularly important towards the end of a furnace campaign ; (*d*) scrap charges should not be dispersed throughout a large number of cars, and ore charges should be increased when operating conditions permit.—M. A. V.

The Physical-Chemical Principles of the Processes of Iron and Steel Production. W. Oelsen. (Kaiser-Wilhelm-Institut für Eisenforschung, Report No. 481 : [Abridged]. Stahl und Eisen, 1948, vol. 68, May 20, pp. 175–186). The author examines the literature and reports the results of new research on the reactions involved in iron and steel production. Solidification diagrams for FeO-rich slags are important in the study of sintering and the following eutectic temperatures were established : FeO–CaO 1075°, FeO–SiO_2 1175°, FeO–2CaO.SiO_2 1260°, FeO–CaO.SiO_2 1160° and 1070°, FeO basic blast-furnace slag 1170°, FeO acid blast-furnace slag 1050°, FeO–CaF_2 1370°, FeO–3CaO.P_2O_5 1370°, FeO–TiO_2 1315°, FeO–Na_2O 950°, FeO–Na_2O.SiO_2 940°, and FeO–Na_3PO_4 1370° C.

In examining blast-furnace reactions the author and H. Maetz found that with intimate mixtures of iron oxides, gangue-like components, and pulverized coke, the reduction of manganese, silicon, and phosphorus, and desulphurization took place much more rapidly at 900° to 1300° C. than at higher temperatures because, in the solid and pasty states, the surfaces of the reacting substances in contact were many times greater than in the liquid state when the iron and slag had separated out.

Data are presented on the distribution at different temperatures of the elements chromium, vanadium, nickel, copper, aluminium, and arsenic between molten iron and slags containing iron sulphide ; in some cases the effect of manganese on this distribution is shown.

The authors and H. Ploum have found that the greater part of the alkali in the slag formed after desulphurization with soda ash can be recovered in the form of sodium sulphate ; in fact, the silicate slag which is left is so low in alkali that it can be returned to the blast-furnace to recover the manganese and iron.

Research work by R. Vogel and others on the behaviour of alloying elements in relation to sulphide slags and their influence on the formation of sulphide inclusions in steel is reported. W. Oelsen has noted that when manganese sulphide is added to iron melts at 1600° C. about 3% MnS is taken up by the iron and any additional quantity forms a liquid MnS-rich slag, but in a nickel melt 20% MnS is easily taken up without any separation of a sulphide layer. Thus the solubility of manganese sulphide in iron–nickel melts increases markedly with increasing nickel.

The formation of sulphide-silicate inclusions in steel is affected by the fact that the separation of iron-manganese silicates from the sulphides is strongly assisted by the oxides alumina, lime, and titania which dissolve only in the silicates.

The properties of basic silicate slags, and the significance of molten phosphate slags in the basic-Bessemer process are also dealt with.

Finally, the solubility of gases, nitrogen in particular, is discussed, and G. Naeser's observation is noted, namely, that when molten iron is treated with gas mixtures such as nitrogen and oxygen, nitrogen and carbon dioxide, and nitrogen and its oxides, no nitrogen is taken up, but with a neutral or reducing mixture such as nitrogen and hydrogen, or nitrogen and carbon monoxide, nitrogen is rapidly absorbed. To obtain the minimum of nitrogen in basic-Bessemer steel the blast should always contain some oxygen or oxidizing gas even as it leaves the metal.—R. A. R.

The Physical Chemistry of Acid Refining Processes (from the Kinetic Point of View). Yap Chu-Phay. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 83–119). The thermodynamics of the acid steelmaking process was studied by following the actual change in the value of the steady-state constants as the heat progresses. A state of complete equilibrium throughout the system is shown to be the summation of the different partial equilibrium states which have been attained. Seven open-hearth heats, typical of American, British, and German practices, were intensively studied, and the rate of attainment of equilibria is viewed as a problem of the rate of FeO diffusion.—R. A. R.

Oxygen Enrichment—Its Effect on Open Hearths. J. S. Marsh. (Steel, 1948, vol. 122, May 3, pp. 112, 115, 118, 120, 122, 125). Tests by the Bethlehem Steel Corporation on 400 heats with oxygen enrichment on five different furnaces have shown that : (1) The maximum rate of production results from an enrichment to about 27% oxygen ; (2) oxygen consumption ranges from 1200 cu. ft./ton for cold charges to half that for high-metal charges ; (3) production increases of 20% to 50%, coupled with fuel savings of 10% to 25%, were obtained on specially supervised heats, but markedly less on unsupervised heats extending nearly over a whole furnace campaign ; (4) variations in results are due to furnace and shop differences ; (5) over-all rate of routine production with oxygen would be less than indicated by the results of tests under special conditions. —J. P. S.

Use of Oxygen for Steelmaking. Methods of Application and Operating Results. A. G. Robiette. (Iron and Coal Trades Review, 1948, vol. 156, May 28, pp. 1103–1106). This paper describes the use of oxygen in the open-hearth steel furnace and the Bessemer converter. It is concluded that there are considerable advantages to be obtained, though not necessarily with existing processes or equipment.—J. P. S.

Use of Aluminium to Control Grain in Steels. J. M. França. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, pp. 442–447 : Instituto de Pesquisas Tecnológicas, Separata No. 181 : Chemical Abstracts, 1948, vol. 42, May 10, col. 2902). The deoxidation of steel with aluminium and its effect on the threshold temperature of grain growth is reviewed. Bessemer steel low in aluminium, copper, nickel, and chromium was refined in a Héroult furnace, and 20-kg. batches were remelted under a reducing slag in an induction furnace with additions of 0 to 0·12% aluminium. Test specimens were forged, normalized, and machined, and grain size at different temperatures was obtained by differential tempering. Additions of 0·035% to 0·12% aluminium were shown to suffice to raise the grain-growth temperature to over 1000°, which corroborates commercial practice. The analytical procedures for Al_2O_3 and for total aluminium are described.

Basic Open-Hearth Slag Control. C. R. Funk. (Blast Furnace and Steel Plant, 1947, vol. 35, Aug., pp. 939–945 ; Sept., pp. 1098–1104, 1136 ; Oct., pp. 1230–1234 ; Nov., pp. 1372–1374 ; Dec., pp. 1490–1497, 1537 ; 1948, vol. 36, Mar., pp. 332–336 ; May, pp. 539–548).

In Part I of this series of seven articles the functions of basic open-hearth-furnace slags and the advantages of slag control are explained, and slag-control methods used in various melting shops are reviewed. Part II deals with the relationship between the chemical composition of the slag and the pancake sample. In Part III a series of heat logs is presented, and the importance of slag conditions in carbon loss and in sulphur and phosphorus elimination is demonstrated. The mineralogical phases of the slags are described in Part IV, and in Part V the relationship of the mineralogical composition to the appearance of the pancake is outlined. Heat logs showing the reduction of chrome oxide to metallic chromium are presented in Part VI, and the mechanism of the reduction under certain conditions is explained. The concluding article, Part VII, is concerned mainly with work sheets for the types of slags most commonly occurring, and also with the properties of good slags.—J. R.

Method for Control of the Slagging Process in the Openhearth Furnaces. Iu. I. Usatenko. (Zavodskaya Laboratoriya, 1947, vol. 13, Dec., pp. 1430–1434). [In Russian].

Melting of Quality Basic Electric Steel. T. V. Simpkinson. (Canadian Mining and Metallurgical Bulletin, 1948, vol. 41, Mar., pp. 127–137). The history of electric-arc steelmaking is outlined, and comparative production data given for Canada and the U.S.A. over the period 1920–1947. The physical chemistry of the process is explained in detail, and melting practice described. M. A. V.

The Elimination of Phosphorus in the Basic Arc Furnace. C. Bradaschia. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, pp. 442–447 : Instituto de Pesquisas Tecnológicas, Separata No. 179 : Chemical Abstracts, 1947, vol. 42, May 10, col. 2900–2901). The variation of carbon, manganese, silicon, sulphur, and phosphorus was followed during the production of S.A.E. 1050 steel in a 1-ton Héroult basic arc furnace, with the particular purpose of explaining the high residual phosphorus sometimes found. It was concluded that basic refractory absorbs phosphous during the oxidizing phase, and returns it to the melt during the reducing phase. Thus low-phosphorus steel is favoured by using low-phosphorus scrap, by using a large volume of oxidizing slag, and by tapping the first oxidizing slag and replacing it with a second.

FOUNDRY PRACTICE

Electric Furnace Production of Cast Iron by the Brazilian Electro-Metallurgical Co., Ribeirao Preto. M. P. Uchoa. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Oct., pp. 667–683). [In Portuguese].

Molten Salt Bath Descaling Provides Greater Metal Savings. (Steel, 1948, vol. 122, Mar. 29, p. 90). Brief particulars are given of a descaling process for large sheets and plates. A large electrically heated tank containing sodium hydroxide with an addition of sodium hydride is held at 700° F. The immersion time is from 8 to 20 min. After rinsing, the material is given a quick acid dip and finally a high-pressure rinse.—R. A. R.

Melting Iron in Gas-Fired Crucibles. (Iron Age, 1948, vol. 161, Apr. 29, pp. 91–93). A foundry at Worcester, Massachussets uses gas-fired crucible furnaces for melting alloy cast irons, producing metal with sulphur as low as 0·04%. Furnaces are gas fired, tilting, and lined with silicon carbide preburned sections backed with rammed insulating material. It has been found possible, once the furnace is hot, to pour 775 lb of metal at 1500° C. 2 hr. 50 min. after charging, with an average consumption of 16·12 cu ft of gas, of 530 B.Th.U./cu ft per pound melted.—J. P. S.

Coke Boosters—A Fallacy in Cupola Operation ? (American Foundryman, 1948, vol. 13, Apr., pp. 137–139). The use of " booster " charges of coke during the operation of cupolas indicates poor procedure, and more advantage would be gained from spreading the same amount of coke over the whole period of operation. Present-day coke in the United States is variable in quality and the cupola operator may have to be satisfied with a lower melting rate.—J. P. S.

The Constant Charge System of Cupola Operation. W. W. Braidwood. (Institute of British Foundrymen: Foundry Trade Journal, 1948, vol. 84, May 6, pp. 435–439; May 13, pp. 465–468). In order to avoid difficulties in cupola operation when demands involve abrupt changes in quality of metal, it is suggested that a standard basic quality be made, and additions introduced as required in the spout or ladle. The standard charge could contain C 3·0–3·3%, Si 1·0–2·0%, Mn 0·6–1·0%, S 0·12% max., and P 0·45 % max. or 0·25% max. if practicable. Full use is made of scrap, provided the phosphorus is not too high. Cost data show that the cost of the charge is only 10*s.* more per ton than a normal charge for phosphoric iron. Silicon is added as ferrosilicon, (although silicon metal, calcium silicide, or exothermic compounds of the "Sil-X" type may be used), nickel as "F" nickel shot, chromium as granulated ferrochromium, or preferably "Chrom-X", and molybdenum as ferromolybdenum. Additions are made in a steady shower to the stream of metal in the spout; they should begin when the bottom of the ladle is covered, and be complete by the time the tapping is two-thirds complete. Typical cupola operating data for various grades of metal are given.—M. A. V.

Notes on the Practice at Argus Foundry. A. Jamieson. (Foundry Trade Journal, 1948, vol. 84, May 13, pp. 471–473). Cupola operation at a grey-iron foundry using the "Constant-Charge" system (*see* previous abstract) is described.—M. A. V.

High Duty Cast Iron in Great Britain. A. B. Everest. (Metalen, 1948, vol. 2, May, pp. 193–195). A brief account is given of the development of high-duty cast irons concluding with some details of acicular cast irons for Diesel engine crankshafts.—R. A. R.

Canadian Steel Foundry Practice. S. L. Gertsman. (Canadian Mining and Metallurgical Bulletin, 1948, vol. 41, Mar., pp. 137–143). Modern Canadian steel-foundry practice is described generally with special reference to melting steel in electric furnaces, moulding, sand quality and control, cleaning, heat-treatment, testing, and quality control.—M. A. V.

Design of Steel Castings. (B.S.F.A. Bulletin, 1946, vol. 1, July, No. 1; Oct., No. 2; 1947, Mar., No. 5; 1947, June, No. 3). The first section deals with the general design and selection of steel for a casting. Bulletin No. 2 describes the use of feeder heads and chills, and gives a short account of the process of solidification of castings. Bulletin No. 5 discusses hot tears and cooling stresses. Bulletin No. 3 discusses mouldability and the use of cores.—C. O.

Chemically Bonded Sand. T. Barlow. (Iron Age, 1948, vol. 161, Apr. 22, pp. 80–83). A new chemically coated sand is now in use in 13 large mechanized foundries in the United States. The coating, a non-thermo-setting hydrocarbon plastic, gives a bonding action even in the absence of clay and water, but these are still used to develop about half the bonding action. Moisture content is therefore reduced to about 3%. It is claimed that the treatment of sand with this coating has enabled a wider range of work to be produced with a given grain-size of sand, and that finer finishes are produced. It is possible, by spraying a mould surface with the resin-chemical solution, to produce skin-dried moulds of great value with patterns giving difficulty in green sand, and it is hoped to extend the technique to the manufacture of cores.—J. P. S.

Modern Foundry Equipment. J. F. Driver. (Machinery Lloyd, 1948, vol. 20, Feb. 28, pp. 79–87: [Abstract]. PERA Bulletin, 1948, vol. 1, May, p. 403). The modern foundry equipment and sources of supply briefly surveyed in this article include sand-testing appliances, drying ovens, aids to metal analysis, melting furnaces, moulding equipment, conveyors, centrifugal-casting machines, and shot-blast and Wheelabrator cleaning equipment.

Dry-Sand Patterns. J. Timbrell, jun. (Foundry Trade Journal, 1948, vol. 84, May 13, pp. 457–461). The production of typical sand patterns, making use of broken castings and core material is described.—M. A. V.

The Loam Moulding of Rope-Barrel Castings. D. Robertson. (Foundry Trade Journal, 1948, vol. 84, Apr. 29, pp. 413–418; May 6, pp. 445–448). The author describes in detail the moulding and casting in loam of four rope-barrels for floating cranes; each was 10 ft. 7 in. in outside dia. and 8 ft. in over-all height, weighing 12 tons 15 cwt when finish-machined.—J. P. S.

Precision Investment Casting. E. L. Cady. (Product Engineering, 1948, vol. 19, Apr., pp. 81–85). The steps to be taken to ensure that investment casting is suitable for the product, and that it offers the desired accuracy in dimensions and surface finish are described.—J. P. S.

A Critical Survey of Investment Casting. R. L. Wood and O. von Ludwig. (Iron Age, 1948, vol. 161, May 6, pp. 72–78; May 13, pp. 90–94, 140, 142). Investment moulding is the most flexible and accurate of precision-casting methods; tolerances obtainable are, however, not as small as those to which machining operations work. Therefore it is, in general, uneconomical to use the process for products of a size, or in alloys, which can be readily machined. In preparing wax patterns it is essential to follow good design rules in allowing fillets, providing feeding facilities for heavy sections, and the stability of the iron during the investment, ageing, and heating of the mould is an important factor. The investments suitable for various alloys, and the appropriate melting processes are described.—J. P. S.

New Centrifugal Process Produces Soil Pipe. R. L. Farabee. (American Foundryman, 1948, vol. 13, Apr., pp. 134–136). This paper describes the use of a split, plain cast-iron mould for the centrifugal casting of 4-in cast-iron soil pipe in 5-ft lengths. A special form of tilting ladle is used which, while decreasing the velocity of iron-flow during the operation, maintains a constant volume rate. Dry sand cores are used to form the hubs for linking up the lengths of pipe.—J. P. S.

The Newcast Foundry. A. R. Parkes. (Foundry Trade Journal, 1948, vol. 84, May 6, pp. 441–444). Plant and operation at a small jobbing foundry, which was erected in less than four months, are described.—M. A. V.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

Production Heat Treating. (Steel Processing, 1948, vol. 34, Mar., pp. 148–153; Apr., pp. 204–208). Modern methods of heat-treatment, including materials handling, atmosphere and temperature control, salt baths, the use of time-temperature-transformation curves, annealing, martempering, treatment at subzero temperatures, material control, and high-frequency induction heating are discussed.—R. A. R.

Industrial Heating Furnaces. (Steel Processing, 1948, vol. 34, Feb., pp. 90–96). This general survey of industrial furnaces gives descriptions and illustrations of several types of heat-treatment furnaces.—R. A. R.

Heating Methods for Controlled Atmosphere Furnaces. W. H. Holcroft and M. R. Larson. (Steel, 1948, vol. 122, Apr. 26, pp. 100–103). For heating in controlled atmospheres, muffles, radiant tubes, both gas- and electrically heated, or open-type electrical resistance units can be used. If gas-fired radiant tubes are employed

a long luminous flame is desirable, with low gas and air velocities to avoid turbulence and consequent hot spots. If electrically heated radiant tubes are used, the enclosing tube protects the element against sulphur attack. Open elements may be used if the atmosphere is sulphur-free and controlled to prevent carbon deposition.—J. P. S.

The Fundamentals of Industrial Furnace Design and Operation. H. Southern. (Ministry of Fuel and Power, Fuel Efficiency Committee Conference on "Fuel and the Future," London, Oct., 1946, vol. 2, pp. 79–92). *See* Journ. I. and S.I., 1947, vol. 155, Feb., p. 306.

Remarks on Electric Furnaces. A. G. Lobley. (Ministry of Fuel and Power, Fuel Efficiency Committee Conference on "Fuel and the Future," London, Oct., 1946, vol. 2, pp. 129–133). The technical advantages of electric furnaces, and steps to be taken to ensure their economical operation, are explained. Energy consumption data are given for typical carburizing, brass annealing, and malleablizing furnaces, and for induction-heated forging and surface-hardening furnaces.—M. A. V.

Electric Furnaces in the Construction of Railway Material. (Revue de Chauffage Électrique, 1946, Nov.–Dec., No. 14, pp. 83–84. The characteristics of resistance furnaces for heat-treatment are given.

Oil Firing in the Ferrous Metals Industry. A. Stirling. (Ministry of Fuel and Power, Fuel Efficiency Committee Conference on "Fuel and the Future," London, Oct., 1946, vol. 2, p. 176). A creosote-pitch-fired heat-treatment furnace is briefly described. The furnace could be fired, if necessary, with a mixture of creosote-pitch and coke producer gas.—M. A. V.

Furnaces and Fuels for Heat Processing Metals. F. E. Harris. (Steel, 1948, vol. 122, May 10, pp. 90–94). Extreme care in heat application, timing, and temperature control are necessary for maintaining acceptable quality in many operations; gas composition and flow also require control to obtain correct atmospheres. J. P. S.

Large Car-Type Furnaces Featured at Pearson Industrial Steel Treating Co. (Industrial Heating, 1948, vol. 15, Jan., pp. 128–134; Feb., pp. 310–316). The annealing, hardening, quenching, and tempering furnaces and equipment at the works of Industrial Steel Treating Co., Cicero, Illinois, are described.—R. A. R.

Heat Treating 54-Foot Alloy Bars. F. H. Bremmer. (Steel, 1948, vol. 122, Apr. 5, pp. 77–78, 101, 102). A plant of the National Supply Co., at Ambridge, Pennsylvania, heat-treats 54-ft lengths of rolled steel bar, 5 in to 9⅝ in in dia. The plant comprises a car bottom furnace, 65 ft. long, fired by natural gas and a quenching tank agitated by motor driven propellers. The oil is kept down to 110° C. by circulation through a water-cooled heat exchanger. The handling gear for these long bars, and the fire-protection apparatus are also described.—J. P. S.

Investigations of the Applicability of Two-Stage Heat-Treatment. W. Connert and H. Kiessler. (Stahl und Eisen, 1948, vol. 68, Apr. 22, pp. 137–151). The properties obtained by the interrupted-quench treatment of a low-alloy steel (C 0·45%, Si 1·4%, Mn 0·9%, Cr. 1·1%) were investigated. The specimens were quenched in a salt bath at temperatures in the 200°–400° C. range and held for different times up to 3 hr. before cooling to room temperature. A marked increase in the toughness at room temperature and lower was noted.—R. A. R.

Catalysis Preparation of Town's Gas for Carburising. (Machinist, 1948, vol. 92, May 15, pp. 65–66). Gas-carburizing with prepared town's gas is described. The Wild-Barfield process catalytically removes carbon-dioxide and oxygen from the gas, lowers the content of unsaturated hydrocarbons and increases carbon monoxide considerably and hydrogen slightly, with little effect on the methane content.—J. P. S.

Whiteheart Malleable. P. F. Hancock. (Iron and Steel, 1948, vol. 21, Mar., pp. 105–108; Apr., pp. 141–144). Two installations for the gas-decarburizing of whiteheart malleable iron castings, their operation, and experience gained from their use are described: in the second part the author considers the control of atmosphere, and operating costs.—R. A. R.

S-Curves and Their Practical Application. K. Schürch. (Schweizer Archiv, 1947, vol. 13, Dec., pp. 379–383). The application of time-temperature-transformation curves to determine heat-treatment conditions is explained with two examples relating to the optimum heat-treatment of welds in a 0·6%-carbon, 3·29%-nickel, 2·22%-chromium steel and a 0·35%-carbon, 13%-chromium steel.—R. A. R.

S-Curves for the Heat-Treatment of Steels. E. Bickel. (Schweizer Archiv, 1948, vol. 14, Feb., p. 60). This note refers to a paper by Schürch (*see* preceding abstract) and briefly explains "isothermal hardening," In this the steel is first held in a bath at just below the martensite change point until temperature equilibrium is reached and then tempered at constant temperature until transformation to troostite is complete.

German terms for "martempering," "austempering," and "isothermal hardening" are proposed.—R. A. R.

The Cooling of Steel with a Tendency to Spheroidization after Hot Mechanical Working. S. A. Iofinov. (Stal, 1948, No. 3, pp. 258–261). [In Russian]. The heat-treatment of steel with a tendency to spheroidization is discussed and some examples, mainly from American practice, are given. The use of heated pits, tunnels and chambers is recommended.—S. K.

The Practical Heat Treatment of High Speed Steel Cutting Tools. W. E. Bancroft and W. W. Wight. (Metal Progress, 1948, vol. 53, Apr., pp. 545–555). The heat-treatment of the tungsten and molybdenum high-speed steels is described in detail. Test-pieces quenched from 75° to 100° F. below the normal quenching temperature and tempered to a hardness of Rockwell C62–63 are measurably tougher than when quenched from the normal temperature and "over-tempered" to the same hardness. Two preheating furnaces operating at 1550° F. will keep one hardening furnace supplied because it takes four times as long to bring a charge up to 1550° F. as it does to raise it from 1550° to the quenching temperature. If normally austenitized high-speed steel is quenched continuously to −100° F. or lower, the amount of untransformed austenite will be about half that which would remain if the cooling were stopped at room temperature. After quenching to −120° F. and double tempering, 18/4/1 high-speed steel has a lower shock resistance than without the subzero treatment. A second tempering tempers and stress-relieves the martensite formed on cooling from the first tempering, and it is not so dependent on time as the first. Double tempering is adequate provided that the holding time in the first is sufficient to cause complete transformation of the residual austenite.

The formation of bainite and the surface treatment of high-speed steels by nitriding and chromium plating are also dealt with.—R. A. R.

Treatment of High-Speed Tool Steels by Low Temperatures. I. B. Levin. (Stanki i Instrument, 1947, vol. 18, Dec., pp. 17–18: [Abstract]. Index Aeronauticus,

1948, vol. 4, May, pp. 62–63). In the annealing of high-carbon and high-alloy tool steels the presence of residual austenite lowers the attainable hardness of the tools. Experiments in Russia indicated that the transformation of the austenite can be completed at low temperatures (below −65° C.) and results in increased hardness and longer life of the tool. In the arrangement adopted the tools were annealed at 560° C. and plunged into an inert gas (liquid nitrogen) at −187° C.

Effect of the Tempering Time on the Hardness of Tool Steel. A. Pomp and A. Krisch. (Kaiser-Wilhelm-Institut für Eisenforschung: [Abridged]. Stahl und Eisen, 1948, vol. 68, Apr. 22, p. 165). Specimens of high-carbon and low-alloy steels were tempered at temperatures in the 50–270° C. range with holding times up to 1000 hr. and hardness determinations were made. With increasing holding time the decrease in hardness was at first rapid and then slower. For all the steel the most rapid change of hardness with time was in the 120–150° C. range; this was followed by the slowest change at 210° C. Long-time tempering had the greatest effect on the unalloyed high-carbon steels. A second tempering at 90° C. had very little effect on the hardness of steels previously tempered at 120–180° C. for 1000 hr.

R. A. R.

The Cold Treatment of Steel. E. G. Thurlby. (Institute of Production Engineers: Australasian Engineer, 1948, Feb. 7, pp. 45–52). After explaining the general theory of heat-treatment, the effects of sub-zero cooling and of tempering before and after sub-zero treatment are discussed. With tempering temperatures between 200° and 900° F. there is no measurable difference between normally heat-treated and sub-zero treated steel, but above 900° F. the sub-zero treated steel is noticeably harder. The claims made for the benefits of sub-zero treatment have been exaggerated, but there is some justification for applying it to high-speed steels which have been heated for hardening under carburizing conditions.—R. A. R.

Cyaniding Paste for Tools. V. A. Ivanov. (Vestnik Machinostroenia, 1947, No. 6, pp. 71–72: [Abstract]. Engineers' Digest (London), 1948, vol. 9, May, p. 172).

Induction Hardening of a Quality Controlled Iron. C. F. Walton and H. B. Osborn, jun. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 491–512). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 532.

Some Factors Affecting the Induction Hardening of an Alloy Cast Iron. J. R. Sloan and R. H. Hays. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 1036–1076). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 532.

The Surface Hardening of Steel by Heating with High Frequency Induction Currents. G. Perronne. (Revue Générale de l'Electricité, 1947, Oct., pp. 412–420: [Abstract]. Science Abstracts, Section B, 1948, vol. 51, Jan., p. 21). The theory is given and the mode of operating the process is described. Electrical, thermal, and metallurgical problems are discussed. Finally, a description of the electric plant necessary is given and results are compared with surface hardening by other processes.

The Applications to Surface Hardening of Induction Heating at Radio Frequency (500 Kilocycles), (Revue de Chauffage Électrique Français, 1946, Nov.–Dec., pp. 81–83: [Abstract]. Aperçu de la Presse Technique, 1948, vol 3, Apr., p. 9. The advantages of using very high frequencies and of using high-frequency induction heating for surface hardening are discussed.

The Stress-Relief Annealing in the Continuous Furnace of Low Carbon Strip Steels Produced by Different Processes. A. Pomp, J. Brockhaus, and G. Niebch. (Kaiser-Wilhelm-Institut für Eisenforschung, Report No. 34: [Abridged]. Stahl und Eisen, 1948, vol. 68, May 20, p. 203). It had proved difficult to produce basic-Bessemer cold-rolled low-carbon steel strip with 60–65 kg/sq mm tensile strength and 10–15% elongation. Tests showed that batch annealing produced the required stress-relief, and that rapid continuous annealing was equally successful if the temperature in the latter case was kept about 100° C. higher than in the former.—R. A. R.

Patenting Processes and Electric Patenting of Wire. J. Reuter. (Boletim da Associação Brasileira de Metais, 1947, vol. 3, Oct., pp. 624–630). [In Portuguese].

The Annealing of Cast Iron in Hydrogen. J. Bernstein. (Journal of The Iron and Steel Institute, 1948, vol. 159, May, pp. 11–15).

Stress-Relief Treatment of Iron Castings. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. B41–B45). *See* Journ. I. and S.I., 1947, vol. 157, Dec., p. 645.

Bright Annealing of Stainless Steels and Nickel–Chromium Alloys. A. Normand. (Métallurgie, 1948, vol. 80, Apr., pp. 17, 19). After reviewing the work of various investigators, the author examines the conditions required for bright annealing various alloys.—J. C. R.

Proper Precautions Eliminate Cracking in Tool Steel Heat Treatment. S. D. Smoke. (Materials and Methods, 1948, vol. 27, Mar., pp. 86–88). The cracking of tool steels during heat-treatment may be avoided by care in preheating, by careful control of the hardening temperature, by proper circulation of the quenching bath, and by adequate tempering.—J. P. S.

Science and Heat Treatments. J. Blandin. (Revue Technique Suisse, 1947, July, pp. 515–522: [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Apr., p. 9). **S**-curves enable the exact structure desired to be obtained by hardening, as they indicate the isothermal hardening (austempering) range. Moreover, as the steel thus hardened is homogeneous, the risk of deformations and cracks is removed.

Minimizing Oil Fire Damage. F. C. Rodgers. (Steel, 1948, vol. 122, Apr., 19, pp. 101–102, 104, 107, 110). This describes a centralized and semi-automatic apparatus using CO_2 to put out oil fires in the quenching baths of forging shops.—J. P. S.

An Evaluation of Quenching Oils by Means of the End Quench Test. C. A. Siebert and G. Sandoz. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2353: Metals Technology, 1948, vol. 15, Apr.). The authors applied the end-quench test to evaluate the hardening power of five different oils representing three sources of supply, finding that two proprietary compounded oils differed in quenching power from each other more than they differed from a straight mineral oil.

Hardening power was increased by increasing the rate of flow of the oil and reduced by increasing its temperature. At a high rate of agitation during quenching, such as the end-quench test gives, proprietary quenching oils have little advantage over mineral oils.

J. P. S.

How to Select Quenching and Tempering Oils for Treating Steel. E. L. H. Bastian. (Steel, 1948, vol. 122, Mar. 22, pp. 64–66, 86–89; Mar. 29, pp. 79–84). The process of heat transfer during the quenching of a steel bar in water is analysed and its three stages are described. These are: (*a*) While the bar is completely surrounded by a thin blanket of vapour; (*b*) when this film is no longer uniformly sustained; and (*c*) when cooling is by conduction through the liquid. Fastest cooling occurs during period (*b*). The cooling velocities for a

number of liquids are given and several methods of evaluating the quenching effects of different media are explained. Finally, martempering, austempering, annealing, and normalizing are discussed.—R. A. R.

WELDING AND FLAME-CUTTING

Electric Flash Welding. (Steel, 1948, vol. 122, May 17, pp. 84, 114). This article describes the gear for welding coils into continuous strip between the pickler and the tandem mill at the Aliquippa Works of Jones and Laughlin Steel Corp. Two 350-kVA welding transformers are used and a pressure of 12,000 lb/sq in is used. J. P. S.

Note on the Use of Single-Run Mild Steel Electric-Arc Weld Metal. (British Engine, Boiler and Electrical Insurance Company, Technical Report for 1938, 1948, pp. 39–46). Examination by Izod and Brinell tests of weld metal laid down in one run in welding 1¼-in mild steel plate, has been made. The results indicate that the metal is up to the standards for refined weld metal. In following out the single-run procedure in practical work, however, it is necessary to ensure that there is no danger of contraction cracks, hardening of the parent metal, or distortion of the part welded. J. P. S.

Explosion of Forge-Welded Air Receiver. (British Engine, Boiler and Electrical Insurance Co., Ltd., Technical Report for 1938, 1948, pp. 56–58). A very destructive explosion in a compressed air receiver 6 ft × 15¼ in, charged to 900 lb/sq in is ascribed to fatigue. The tendency of the cylinder to "barrel" on being charged caused a severe concentration of stress at the edge of the welded joint between the sides and top; repetition of this ultimately, *i.e.*, after 27 years, led to failure.—J. P. S.

Ore and Coal Bridges. G. F. Wolfe. (Iron and Steel, 1948, vol. 21, May 13, pp. 189–195). The construction, mainly by welding, of an ore bridge 575 ft long, 51 ft 6 in from rail level to the bottom of the span, with a 15-ton grab, is described.—J. P. S.

The Manufacture and Application of Composite Plates. O. R. Carpenter. (Welding Journal, 1948, vol. 27, Apr., pp. 279–287). This paper describes a number of methods for coating alloy steels on carbon steels. The newest of these is resistance seam welding where the coating metal is fixed to the base-plate by overlapping spot welds. A layer of nickel sheet placed between the base and the casting not only greatly assists bonding but also reduces the danger of carbon-migration from the base.—J. P. S.

Resistance Welding in Mass Production. A. J. Hipperson and T. Watson. (Welding, 1948, vol. 16, Mar., pp. 121–125; Apr., pp. 145–151, 162). Conclusion of a series of articles (*see* Journ. I. and S.I., 1948, vol. 159, May, p. 96). The principles of butt and flash welding are explained, their advantages for particular applications are pointed out, and a number of butt and flash-butt welding machines are described.—R. A. R.

Flame-Gouging or Scarfing. T. H. Neijboer. (Lastechniek, 1948, vol. 14, May, pp. 61–66). [In Dutch].

Preparing Mild-Steel Plates for Welding by Means of Flame-Cutting. (British, Engine Boiler and Electrical Insurance Co., Ltd., Technical Report for 1938, 1948, pp. 17–28). Investigations were carried out to determine the effects of oxy-acetylene cutting the edges intended for butt welding; it is concluded that with a suitable flux-coating, the scale produced by flame-cutting can be removed in welding. The edge produced by hand-flame-cutting is rougher than that produced by machine-cutting, but this is no detriment where the welding rod gives adequate penetration. Severe irregularities may be smoothed down by grinding.—J. P. S.

Blow Pipe Cutting Used to Reclaim Ladle Skulls and Buttons. (Steel, 1948, vol. 122, May 17, pp. 94, 97). An accumulation of skulls from ladles and buttons from slag-ladles estimated at 15,000 tons is being cut up either by water-cooled blowpipes or by blasting, the holes being pierced with the oxygen lance.—J. P. S.

CLEANING AND PICKLING

Surface Treatment for Metal before Painting. A. P. Schulze. (Industrial Finishing, 1948, vol. 24, Feb., pp. 48, 52–56, 61–66).

Electropolishing—A Survey. S. Wein. (Metal Finishing, 1948, vol. 46, Apr., pp. 76–82). This is the concluding part of a series. (*See* Journ. I. and S.I., 1948, vol. 159, June, p. 223). The applications of the electropolishing process are described, and working characteristics of the various baths discussed. Detailed notes are given on the electropolishing of various metals, including carbon steels, stainless and other alloy steels. General operating data are given, with some typical costs for the various metals.—M. A. V.

An Analysis of the Polishing Problem. W. H. Sawyer. (Journal of the Electrodepositors' Technical Society, 1948, vol. 23, pp. 59–78). The author considers that many of the problems of polishing arise from earlier stages in the manufacturing process, and calls for more care in these earlier stages. He also demands a more careful study of the polishing process itself.—J. P. S.

Methods and Technique of Automatic Polishing. H. C. Clements. (Journal of the Electrodepositors' Technical Society, 1948, vol. 23, pp. 79–80). This paper describes the general principles of machines for the automatic polishing of tube, rod, sheet, strip, and manufactured articles such as cycle rims, torch cases, car door-handles, and light pressings.—J. P. S.

Electrochemical Cleaning of a Large Steel Casting—An Experiment. J. A. Wettergreen. (American Foundryman, 1948, vol. 13, Apr., pp. 120–124). A large cast steel turbine shell was cleaned of fused sand and oxides by preheating to 400° C. and immersing in molten caustic soda at 400–450° C.; cleaning was electrolytic, copper bars being used as counter-electrodes. The casting was made anodic for 3 min., with 2200 amp passing; polarity was then reversed and 4000 amp at 6–7 V passed for 2 hr. Inspection was then made and the casting treated for a further 2½ hr.

After removal, and washing with a fire-hose, it was found that nearly all the fused sand had been removed, while the "penetrated metal" *i.e.*, a hard and adherent mixture of fused sand and metal globules, had been reduced to a state in which it could be readily removed. Oxide scale resulting from previous flame-cutting operations was also cleanly removed.—J. P. S.

Sodium Hydride Effective in Descaling Stainless Steel Sheets. M. H. Lebowitz. (Steel, 1948, vol. 122, Apr. 5, pp. 107, 110, 112). At the Wood Works of the Carnegie-Illinois Steel Corporation, McKeesport, Pennsylvania, many types of stainless steel are descaled in molten caustic soda impregnated with sodium hydride. The sodium-hydride generators consist of open-bottomed cylinders standing in the caustic-soda bath; metallic sodium in 3-lb. blocks is dropped in periodically and reacts with hydrogen produced in a separate building by the dissociation of ammonia with a nickel catalyst. The sodium hydride then diffuses into the caustic soda and is maintained at a concentration of 1·5–2·0%. Stainless steel sheet can be descaled at the rate of 4½ tons/hr. J. P. S.

Detergent Additions Improve Pickling Bath Efficiency. (Iron Age, 1948, vol. 161, Apr. 29, p. 77). A complex organic sodium sulphate known as Nytron, developed

by Solvay Process Co., New York, acts as a wetting agent, and, by reducing " drag-out " in passing from an acid-pickling bath to a soda neutralizing bath, conserves acid and alkali. It also produces a foam blanket on the bath which eliminates gassing.—J. P. S.

Some Suggestions for the Disposal of Ferrous Sulphate from Waste Pickle Liquor. P. de Lattre. (Sheet Metal Industries, 1948, vol. 25, Apr., pp. 697–703, 716). Methods of treating ferrous sulphate from waste pickle liquor and the market for the products are reviewed. The methods of using ferrous sulphate to make Prussian blue, zinc sulphate, ferric sulphate and chlorinated ferric sulphate, sulphuric acid, and sulphate of ammonia, are described. If all firms were forced to stop throwing away spent acids there would be two ways of avoiding over-production of ferrous sulphate, namely, conversion into sulphuric acid, and production of ammonium sulphate. Production of sulphuric acid by adding ferrous sulphate to the pyrites in the ordinary process involves the complete loss of ferric oxide as it is mixed with the very impure oxides from the pyrites. Another possibility would be the establishment of a large central sulphuric acid plant taking the ferrous sulphate output of many works. The advantages and disadvantages of this are considered. The production of ammonium sulphate using ammonia from coke-oven gas gives ferrous hydroxide and its conversion into high-grade red pigments would be interesting. In general, the substitution of ferrous sulphate for sulphuric acid in the manufacture of ammonium sulphate is not considered to be economic. R. A. R.

Treatment of Spent Pickle Liquor. N. Swindin. (Transactions of the Institution of Chemical Engineers, 1944, vol. 22, pp. 56–71). *See* Journ. I. and S.I., 1944, No. II, p. 83A.

The Rôle of the Inhibitor on the Fixation of Hydrogen by Polycrystalline Iron during Acid Pickling. L. Moreau. (Métaux, Corrosion, Usure, 1944, vol. 19, Mar.–Apr., pp. 49–50). Surface hardness was measured and plotted as a function of the period of pickling in 10% HCl. When 2% pyridine was present as an inhibitor, hardness increased constantly as atomic hydrogen was absorbed into the lattice, but when no inhibitor was present surface hardness decreased. In further experiments bend tests were made on extra mild steel wire after pickling. When an inhibitor was present brittleness increased very slightly and when the wire was placed in a vacuum there was a small evolution of hydrogen at ordinary temperature. When there was no inhibitor, brittleness was more pronounced and increased with the duration of pickling, and when the wire was placed in a vacuum there was a considerable evolution of hydrogen from intergranular areas. Variations of the mechanical properties of polycrystalline iron pickled in a solution containing an inhibitor were identical with those of monocrystalline iron attacked by the same pure acid solution. It was concluded that the inhibitor was adsorbed at the intercrystalline boundaries, and suitable pickling inhibitors were those substances known to inhibit the action of metallographic reagents which clearly show the grain boundaries.—J. C. R.

Stripping of Electrodeposits. N. D. Hoffman. (Plating, 1948, vol. 35, Apr., pp. 351–352, 404). Immersion and electrolytic type stripping baths are described; the former include chromic-sulphuric acid for removing copper or cadmium from steel; full-strength HCl (not recommended) for removing zinc or cadmium from unbuffed steel, and chromium from brass, copper, or nickel; and inhibited HCl for removing cadmium or tin from steel, brass, or copper, and zinc or cadmium from cast iron. The electrolytic baths are sodium nitrate for removing nickel or copper from steel; H_2SO_4 for removing nickel from brass, copper, or copper-plated zinc-base die castings; sodium cyanide for removing brass, bronze, copper, cadmium, zinc, gold, or silver from steel; and " reverse cleaner " for removing tin from steel, brass, bronze, or copper, and chromium from steel or nickel.—M. A. V.

De-Enamelling of Sheet Steel Parts. A. Kelly. (Journal of the Canadian Ceramic Society, 1947, vol. 16, p. 45: British Ceramic Abstracts, 1948, Jan.–Feb., p. 29A). For the removal of vitreous enamel from sheet steel for re-enamelling, so that a rejected article can pass inspection, sand-blasting, acids, and alkalis used in various ways leave much to be desired. A diagram illustrates a de-enamelling tank in which a solution of flaked caustic soda at 280° F. is used, and the operation is described.

Austenitic Stainless Wire Cleaning. (Wire Industry, 1948, vol. 15, Apr., p. 243). The development of pickling solutions for stainless steel wire is outlined. A nitric-hydrofluoric solution is now recommended; if scale is heavy, this may be preceded by a pre-pickle in a solution of 6–9 parts H_2SO_4 and 2–4 parts HCl in 100 parts water (by volume). Chromium oxide scale is impervious to acid and must be removed by abrasion. A new pickling bath now popular in the United States is a solution of 6–7% " Ferrisul " (anhydrous ferric sulphate) and 1·5–2% hydrofluoric acid, which is non-fuming, non-corrosive, and has a low rate of metal attack provided the two constituents are kept in balance.—M. A. V.

Application of Hydro-Blast to Dressing and Sand Recovery. W. Y. Buchanan. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. B110–B119). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 293.

Cleaning Surfaces by Non-Erosive Blasting. J. Albin. (Metal Finishing, 1948, vol. 46, Mar., pp. 54–56, 61). Seed-blasting covers the use of hominy grits, peanut shells, coffee grounds, ground walnut shells, and plastic grits, for use in conventional sand-blasting equipment for cleaning engine parts without causing abrasion. Some account is given of the relative costs of these materials, their resistance to repeated use, the precautions required in storage, and their advantages over sand-blasting where machined surfaces and threads are involved.—J. P. S.

PROTECTIVE COATINGS

Selection of Protective Coatings for Metals. K. G. Compton. (Corrosion, 1948, vol. 4, Mar., pp. 112–122). Coatings are classified as metallic (noble and sacrificial), organic, and inorganic. Methods of testing, and the properties and applications of each type are outlined. M. A. V.

Plating Technique for Rebuilding Aircraft Engine Parts. J. Albin. (Iron Age, 1948, vol. 161, May 6, pp. 82–85). At the American Airlines repair base at Tulsa a variety of electroplating methods are employed. Crankshaft bolts are plated with tin over silver over a copper flash; tin prevents galling or sticking while the silver coating, by deforming, helps to distribute assembly stresses. Bearing surfaces are plated first with lead and then with indium; heat-treatment at 177° C. causes the indium to diffuse into the lead, giving a harder and more corrosion-resistant surface. Tappet-roller surfaces are built up with silver, and the internal surfaces of rocker-arms and propeller bearings with copper. For all these processes jigging arrangements have been elaborated, and these are described.—J. P. S.

Rectifiers for Electroplating. L. W. Reinken. (Metal Finishing, 1947, vol. 45, Feb., pp. 73–77; Apr., pp. 58–62; May, pp. 72–74; June, pp. 88–90; Sept., pp.

75–78; 1948, vol. 46, Mar., pp. 57–61). This paper describes metal rectifiers and their associated transformers and controls, for use in electroplating and anodizing.—J. P. S.

Laboratory Tests and Equipment. J. B. Mohler and H. J. Sedusky. (Metal Finishing, 1948, vol. 46, Feb. pp. 50–55; Mar., pp. 76–83). Methods of determining the specific gravity of solutions for plating chromium, copper, nickel and silver, and for ascertaining the conductivity and throwing power of solutions, and current density are given in the first part, whilst the second deals with tests of the deposited metal for adhesion, by bending, burnishing, and similar methods, for hardness, by the usual and microhardness tests, for thickness by chemical or anodic stripping, for porosity by ferroxyl-, electrographic, and copper-immersion tests and for corrosion resistance by salt-spray and outdoor corrosion tests.—J. P. S.

An Electrolytic Thickness Tester for Plated Metal Coatings. H. T. Francis. (Journal of the Electrochemical Society, 1948, vol. 93, Mar., pp. 79–83). This thickness tester operates by the anodic dissolution of a defined area of the plated metal and uses the product of current and time as a measure of thickness. The stripping current is held constant and the removal time automatically indicated. It is necessary that the coating be anodic to the base metal in the electrolyte employed and that it dissolves at 100% current efficiency. Constant stripping voltage is maintained by a 90-V battery which, when stripping is complete and the stripping-cell voltage consequently rises, operates an electronic relay, opening the circuit, and stopping a clock.—J. P. S.

Porosity of Electrodeposited Metals. N. Thon and E. T. Addison, jun. (Monthly Review of the American Electroplaters' Society, 1947, Apr., pp. 445–453; May, pp. 568–576; June, pp. 722–730, July, pp. 831–842). The first part of this series consists of a bibliography on the porosity of electrodeposited metals for the period 1887–1946. In the subsequent parts the literature is critically reviewed.—R. A. R.

Application of Metallic Coatings. R. Mansell. (Metal Finishing, 1947, vol. 45, May, pp. 62–65; June, pp. 91–94). An elementary account is given of the principles of corrosion, the preparation of metals for electroplating, and the plating process.—R. A. R.

Gas Utility Underground Pipe Corrosion Mitigation Practices. A. H. Cramer. (Corrosion, 1948, vol. 4, Feb., pp. 72–82). The procedure adopted by a gas company in detecting faults in the protective coating on steel mains is described, and an analysis given of the types of fault occurring over a period of about five years. The use of a Pearson fault locator is considered indispensable; but this is regarded as an adjunct, and not an alternative, to more conventional types of holiday detector.—M. A. V.

Economical Rinse Tank Design. J. B. Mohler. (Iron Age, 1948, vol. 161, Apr. 15, pp. 76–77, 140). The design of single and multiple rinsing tanks for electroplating plants is discussed and designs are shown which distribute the flow of water in various ways to suit particular requirements. Calculations of tank size and rate of flow adequate for dealing with the intake of solution with the plated articles are explained.—R. A. R.

Chromium Plating at Siemens and Halske, A.G., Berlin, Germany. (British Intelligence Objectives Sub-Committee, 1947: F.I.A.T. Technical Bulletin T-21: H.M. Stationery Office). Working details are given of (*a*) bright chromium plating on aluminium, (*b*) hard chromium plating on iron in a sulphuric acid bath, and (*c*) hard chromium plating on iron in a hydrofluoric-acid/silicofluoric-acid bath. These include in the last two cases, details of the mechanical cleaning, degreasing, and acid etching; bath compositions; and electrical data. M. A. V.

Chromated Protein Films for the Protection of Metals. A. Brenner, G. Riddell, and R. Seegmiller. (Journal of the Electrochemical Society, 1948, vol. 93, Mar., pp. 55–62). Steel, zinc, aluminium and brass may be protected from corrosion by the inhibiting effect of chromic salts in protein films. These chromated films may be applied by dipping in either a one-stage process where the coating solution contains 10% protein (albumin, casein, or gelatine), 0·5% ammonia, and 0·2–0·3% zinc dichromate in water, or in a two-stage process where the first solution consists of 10% protein, 0·5% ammonia, and 0·02% potassium dichromate and the second a 5% solution of zinc dichromate. In the one-stage process, the article is simply dipped, drained, and dried; in the two stages, it is dried between dips and after the second dip. In both cases, the films may be exposed to light to diminish their solubility in water. The chromates act as (*a*) inhibitors, (*b*) hardening agents, and (*c*) bactericides. Water-insoluble proteins such as the corn product zein may be used, although the complexity of the solution, requiring an organic solvent, a stabilizer, a plasticizer, a corrosion inhibitor, and a non-gelling component is a disadvantage.

These protein films have good corrosion resistance, dependent, however, upon the length of time the chromate can be retained and are thus excellent for indoor storage or mild outdoor conditions where leaching-out will not occur.—J. P. S.

Chromizing of Steel. H. Kalpers. (Technik, 1948, vol. 3, Mar., p. 116). A very brief description of the B.D.S. (Becker, Daeves, and Steinberg) process of chromizing is given. Ceramic material is made active by chromium chloride and the steel to be treated is packed in it and heated in a furnace. A chromium concentration of up to 35% can be obtained at the surface. High carbon steels are not suitable for this treatment.—R. A. R.

Materials and Requirements for Decorative and Protective Plating. N. G. Meagley. (Materials and Methods, 1948, vol. 27, Mar., pp. 80–82). This paper describes the plating materials used for a number of applications in the automobile industry: on decorative steel parts and zinc alloy die-castings, copper plus nickel plus bright chromium; on copper and copper alloys, nickel plus bright chromium, on non-decorative parts, cadmium or, in the case of battery bolts, lead.—J. P. S.

The Leafing and Flaking of Nickel Coatings. T. Richards. (Metalloberfläche, 1947, vol. 1, July, pp. 173–176; Aug., pp. 197–199). The causes of the flaking of nickel coatings are considered.—R. A. R.

Hardness Conversion Chart for Nickel and High-Nickel Alloys. F. P. Huston, jun. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 770–781). A correlation technique for hardness data is described. A procedure for classifying such data is given and linear relationships are established and least-squares equations calculated from the classified data. A hardness conversion chart for nickel and high-nickel alloys, established by the above method, is presented. This chart is considered valid for the range of hardnesses normally encountered on such materials. R. A. R.

Uniform Tank Coatings Produced by Controlled Automatic Hot Dip Galvanizing Process. R. W. Thrasher. (Steel, 1948, vol. 122, Apr. 19, pp. 76–80, 112, 114). Hot water storage tanks, range boilers, water softener barrels, etc., are hot-dip galvanized and assembled by resistance welding. Photomicrographs indicate that

the welds of the galvanized material are very good, all indications of the presence of the zinc layer disappearing in the middle portion of the weld.—J. P. S.

The Production of Flexible Zinc Coatings. H. Bablik. (Corrosion and Material Protection, 1948, vol. 5, Mar.–Apr., pp. 8–9). In normal hot-dip galvanizing a number of brittle iron–zinc layers are formed between the base metal and the zinc outer layer. The formation of these layers can be inhibited by the addition of aluminium to the bath. It is, however, necessary to apply a dry flux to the surface of the sheets to be galvanized, before they enter the bath. Though output by this method is less, sheets are produced capable of enduring moderately severe forming operations. The ductility of the zinc layer is higher if it is free from lead or cadmium. J. P. S.

The Deposition of Pure Boron. Part III.—A Flow Method for the Preparation of Boron Films on Iron Cylinders. H. I. Schlesinger, G. W. Schaeffer, G. D. Barbaras, and J. D. Farr. (U.S. Atomic Energy Commission, 1944, MDDC-1340).

Metal Spraying. J. Püschel. (Werkstatt und Betrieb, 1948, vol. 81, Mar., pp. 69–70). This is a general description of the equipment and process for metal spraying with special reference to its usefulness in Germany at the present time.—R. A. R.

The Field and Functions of Flame Spraying. H. W. Greenwood. (Machinery Lloyd, 1948, vol. 20, Feb. 21, pp. 65–67 : [Abstract]. PERA Bulletin 1948, vol. 1, May, p. 436). This article summarizes the present application and the future possibilities of the flame-sprayed powder process. The spraying of anti-corrosive coatings of aluminium or zinc on large areas has proved particularly effective. Any metal with a melting point below 1400° C. may be flame-sprayed as well as the non-metallic materials, Polythene, Thiokol, synthetic rubber, shellac, ebonite, sulphur, and bitumen.

How to Choose the Correct Type of Porcelain Enamel for Specific Applications. J. E. Hansen. (Porcelain Enamel Institute : Products Finishing, 1948, vol. 12, Jan., pp. 28–52). *See* Journ. I. and S. I., 1948, vol. 159, May, p. 98.

Vitreous Enamelling of Chemical Plant. J. D. Currie, (Proceedings of the Institute of British Foundrymen. 1946–47, vol. 40, pp. B99–B109). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 316.

Glass-Enamelled Steel Equipment for the Chemical Industry. J. M. Pirie. (Transactions of the Institution of Chemical Engineers, 1944, vol. 22, pp. 155–160). Methods of enamelling steel and fusing coatings on the interior of vessels are described with details of testing, making joints, and examples of the use of enamel-lined equipment.—R. A. R.

Glycerine in Finishes for Metal Products. G. Leffingwell and M. A. Lesser. (Products Finishing, 1948, vol. 12, Apr., pp. 46, 48, 50, 52, 54). The development of plastic coatings formed from glycerine and alkyd resins is reviewed.—M. A. V.

The Measurement of Paint Film Thickness. F. Fancutt and J. C. Hudson. (Paint Technology, 1948, vol. 13, No. 146, Reprint). The Armament Research Department thickness tester and the electromagnetic thickness tester of the Dutch Corrosion Committee (Central Instituut voor Matereaalunderzoek) are described. The former uses a weighted lever to pull a permanent magnet off the painted steel surface ; the distance of the weight along the lever arm is a measure of the thickness. In the latter a standardized current forces the armature of an electromagnet against the surface to be measured, in opposition to a spring and counterpoise weight ; the current is reduced until the armature leaves the plate, when the current is read off, and a calibration curve is used to indicate thickness. Both instruments have limitations in that they need calibrating before use, are inaccurate on rough, soft, or curved surfaces and only operate on non-magnetic films on magnetic materials, where they may also be disturbed by variations in the base metal. Over a range of 1–8 mils. thickness the Dutch instrument is comparable with that of the ARD, the accuracy being $\pm 10\%$ or better. Except for the fact that it may be used in positions other than the horizontal, it has no advantages, whilst it is less robust and requires more complicated apparatus and careful setting.—J. P. S.

Plastics for Corrosion Control. J. W. Shackleton. (Corrosion, 1948, vol. 4, April, pp. 172–178). This paper describes a number of plastic materials suitable for plating barrels and tanks, and some methods of applying them, *e.g.*, in sheet, as coatings dispersed in organic media, and by flame-spraying from the powder form.—J. P. S.

Antifouling Paints. Preparation of Thin, Lightweight Paints for Application to High Speed Surfaces. A. L. Alexander. P. King, and J. E. Cowling. (Industrial and Engineering Chemistry, 1948, vol. 40, Mar., pp. 461–464). As a result of tests on anti-fouling paints of a variety of compositions, it is concluded that mercurial chloride is at least as effective a toxic as cuprous oxide, and permits a greater latitude in colour design. Films 2 mils. in thickness, containing 8% of mercurous chloride, and over 30% of pigments, gave excellent protection for periods up to six months. Copper resinate produced excellent dispersion, and packaged paints were free from caking and settling. Chlorinated rubber, when modified so as to have the necessary flexibility, was the best matrix and synthetic chlorinated rubbers were better than the natural product.—M. A. V.

PROPERTIES AND TESTS

An Experimental Study of the Propagation of Plastic Deformation under Conditions of Longitudinal Impact. P. E. Duwez and D. S. Clark. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 502–532). *See* Journ. I and S.I., 1947, vol. 157, Sept., p. 152.

The Velocity Aspect of Tension-Impact Testing. W. H. Hoppmann. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 533–544). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 152).

Influence of Metallurgical Factors on the Mechanical Properties of Steel. S. A. Herres and C. H. Lorig. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 775–812). *See* Journ. I. and S.I., 1948, vol. 158, Mar., p. 408.

The Study of Surface Conditions and Properties of Metals. A. Portevin. (Mémoires de la Société Royale Belge des Ingénieurs et Industriels, 1948, Series B, No. 3, pp. 267–279). The work of various investigators on the surface conditions and properties of metals is reviewed.—R. F. F.

Generalized Mechanical Properties of Solid Bodies. J. B. Friedmann. (Comptes Rendus de l'Académie des Sciences, U.R.S.S. (Doklady), 1947, vol. 55, Mar. 30, No. 9, pp. 817–820 : [Abstract]. Applied Mechanics Reviews, 1948, vol. 1, Feb., p. 48). This article presents results of tests on duralumin, high-strength aluminium–zinc–magnesium alloys, austenitic 18/8 steels and high-strength steel of the Chromansil type. By plotting the "generalized" quantities of Ludwig, maximum shear stress against maximum shear strain, the author endeavours to show that the experimental points

for several modes of loading (tension, compression, torsion, double shear) can be represented by a single curve for any one material. This is successfully done for all the materials tested except the high-strength steels, which show consistent anomalies between the tensile and torsional loadings. For all but these latter materials the "generalized shearing strength" (the value of the maximum shear stress at shearing rupture) are practically independent of the mode of loading.

Tempering Effects and the Mechanical Equation of State. J. C. Fisher and C. W. MacGregor. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 302–314). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 531.

The Phase Rule and Its Applications in Metallurgy. W. G. Whittleston. (New Zealand Engineering, 1948, vol. 3, Mar. 10, pp. 274–276). The author gives a simple explanation of the phase rule, illustrated with references to the water–ice–vapour, sulphur, tin–lead, tin–magnesium, nickel–copper and iron–carbon systems.

Effects of Grinding on Physical Properties of Hardened Steel Parts. H. E. Boyer. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 491–512). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 540.

Determination of the Mechanical Properties of Steel without Use of Tensile Specimens. M. F. Sichikov, B. P. Zakharov, and Iu. V. Kozlova. (Zavodskaya Laboratoriya, 1947, vol. 13, Dec., pp. 1463–1471). [In Russian].

A Study of the Transition from Shear to Cleavage Fracture in Mild Steel. H. E. Davis, E. R. Parker, and A. Boodberg. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 483–501). Over ranges of temperature within which there occurred the transition from ductile shear-type failures to brittle cleavage-type failures, three types of specimens of three mild steels were tested: (*a*) Unnotched cylindrical tension bars, (*b*) 3-in. wide flat bars with saw-cut notches in each edge; and (*c*) 12-in. wide plates with a central notch at the mid-section. The mechanism of fracture is discussed in relation to the variation in shear and cleavage strength with temperature and to the state of stress as inducted by notching or deformation. Prestraining at a higher temperature was found to have an important influence on the cleavage strength which in turn affected the ductility at low temperatures. Depending upon the severity of the notch, through its influence on the state of stress and on the extent of plastic deformation before a crack is developed, the transition temperature of a mild steel may range from normal atmospheric to that of liquid air.

Development of Cleavage Fractures in Mild Steels. A. B. Bagsar. (Welding Journal, 1948, vol. 27, Mar., pp. 97-s–123-s). The susceptibility of several types and thicknesses of mild steel ship- and pressure-vessel-plates, and of welds to the development of cleavage or brittle fractures has been determined by a new type of test, the cleavage-tear test, employing a notched tensile-bend type of specimen. The effects of notch and specimen shapes, load eccentricity, rate of loading, testing temperature, and of heat-treatment were investigated. Two types of fracture were encountered, brittle or cleavage fractures, and shear fractures. Above the transition range, stated to be about 100° F. higher when determined by this method than when determined by conventional Charpy tests, shear fracture occurs, below this brittle fracture. The author suggests that to minimize the danger of cleavage fractures in monolithic structures arising from small stress raisers, factors of safety should be raised and modifications of design and material introduced.—J. P. S.

Cleavage Fractures and Transition Temperatures of Mild Steels. A. B. Bagsar. (Welding Journal, 1948, vol. 27, Mar., pp. 123-s–131-s). By use of the "cleavage-tear" test, employing either eccentric loading of a notched tensile specimen or notched simple beams, the author has investigated the temperature of transition from brittle to shear type of fracture. He concludes: (1) That this test is capable of determining transition temperatures and that these, while not fixed, and depending on the notch root radius, can, within certain limits, be correlated with the indications of the conventional Charpy impact test, as well as with service conditions; (2) that service failures in monolithic structures originate in small defects or discontinuities which in certain orientations may reduce the tensile strength of steel by 60% as well as raise the transition temperatures above atmospheric temperature; and (3) that modification of design, welding details and material specifications may be required and that service and loading conditions may be modified to reduce excessive stressing.

J. P. S.

Stress-Rupture Characteristics of Various Steels in Steam at 1200° F. J. T. Agnew, G. A. Hawkins, and H. L. Solberg. (Purdue University, 1947, Engineering Experiment Station Research Series No. 101). The experiments described were carried out on the following nine steels: Low-carbon, carbon/½%-molybdenum, ¼%-chromium/1%-molybdenum, 5%-chromium/½%-molybdenum/1¼%-silicon, 9%-chromium / 1%-molybdenum / ½%-silicon, 12%-chromium / low-nickel, 23%-chromium / 20%-nickel, 18%-chromium / 8%-nickel, 5%-chromium /½%-molybdenum / ½% titanium. Small tensile-test specimens were placed in a steam reaction chamber at 1200° F. and stressed in tension for periods ranging from 10 hr. to 7700 hr. The time to fracture, elongation, reduction of area, depth of scale layer, and type and angle of fracture were noted, and a micrographic study of the ruptured specimens was made. The straight-line relationship between stress and time to rupture on log-log co-ordinates postulated by White, Clark and Wilson for tests in air also holds good for tests in steam.

A. E. C.

Intercrystalline Cohesion and the Stress-Rupture Test. H. H. Bleakney. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 575–595). *See* Journ. I. and S.I., 1947, vol. 157, Sept., p. 152.

The Effect of Non Uniform Distribution of Stress on the Yield Strength of Steel. D. Morkovin and O. Sidebothom. (University of Illinois Engineering Experiment Station Bulletin Series No. 372, 1947). Tests made by the bending of beams and by tensile tests on specimens containing a hole, a notch or a fillet have shown (*a*) that in steels not exhibiting a definite yield point in tension the outer fibres of a beam in bending start to yield when the stress reaches a value equal to that at which the same steel yields under a uniform tension; (*b*) that the same is true for steels not exhibiting an upper yield point; (*c*) that in a tension member of a steel not exhibiting an upper yield point, containing non-uniform and non-linear stress distribution, due to the presence of a hole, notch or fillet, yielding occurs in the most-stressed fibres at a stress equal to the yield point in a tension test with uniform distribution; (*d*) that whilst in some ductile materials tested in tension and free from stress raisers an upper yield point of variable magnitude may be found, yet, although in general the first plastic yielding under non-uniform distribution of stress will also correspond with their upper yield point as determined from uniform distribution, in certain circumstances it will be greater; this is ascribed to the effect of certain factors in the carrying out of the tensile test, *e.g.*,

alignment, radii of fillets and rigidity of the machine, in reducing the upper yield point ; (*e*) that the magnitude of the greatest upper yield point is influenced by the shape of cross-section which determines the upper limiting bending moment for which the beam is stable after initial plastic action.—J. P. S.

Influence of Plastic Extension and Compression on the Fracture Stress of Metals. D. J. McAdam, jun., G. W. Geil, and W. D. Jenkins. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 554–574). *See* Journ. I and S.I., 1947, vol. 157, Nov., p. 475.

Tensile Strength of Case-Hardened Layers. A. M. Paly. (Zavodskaya Laboratoriya, 1946, No. 11–12, pp. 987–988 : [Abstract]. Engineer's Digest (N.Y.), 1948, vol. 5, Mar.–Apr., p. 155).

Ductility of Crankshafts. (British Engine, Boiler and Electrical Insurance Co., Ltd., Technical Report for 1938, 1948, pp. 85–86). It is suggested that elongation is not as good a measurement of ductility as reduction of area, and that the latter gives an indication of capacity for bending. The material of a crankshaft, while meeting the specification for elongation (18%), gave only 21·5% reduction of area and proved to have an Izod value of only 7 ft.lb.—J. P. S.

Determination of the Breaking Strength of Hard Annealed Steel. G. N. Margolin, B. A. Prozdovskii, and P. I. Orlets. (Zavodskaya Laboratoriya, 1947, vol. 13, Nov., pp. 1387–1399). [In Russian].

Ductility of Steels for Welded Structures. A. B. Kinzel. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 27–82). *See* Journ. I. and S.I., 1948, vol. 158, Mar., p. 410.

A Study of Slotted Tensile Specimens for Evaluating the Toughness of Structural Steel. H. R. Thomas and D. F. Windenburg. (Welding Journal, 1948, vol. 27, Apr., pp. 209-s–215-s). Tensile tests of specimens slotted and notched in a variety of ways indicated : (1) Slotted plates notched at the ends of the slot will indicate a transition temperature for the particular shape of the plate and notch ; (2) Plates containing slots notched with a jeweller's saw are more sensitive than plates containing slots notched with drilled holes ; (3) transition temperatures can be determined in plates containing slots of length of one quarter the width of the plate ; (4) diagonal slots and notches exhibit increased values of energy absorption and greatly decreased values of transition temperature, compared with slots perpendicular to the face of the plate, possibly owing to a reduction of the degrees of triaxiality of stress at the ends of the slot. In view of this last conclusion the authors suggest that engineers should take advantage of this effect in designing parts involving abrupt changes in section.—J. P. S.

A Method of Evaluating Transition from Shear to Cleavage Failure in Ship Plate and Its Correlation with Large-Scale Plate Tests. N. A. Kahn and E. A. Imbembo. (Welding Journal, 1948, vol. 27, Apr., pp. 169-s–182-s). The authors' tear test to determine the susceptibility of ship plate to brittle or cleavage fracture uses a notched 3 × 5-in specimen of the plate which is asymetrically loaded under static tension and controlled temperature conditions to complete failure. A load-extension diagram is obtained which indicates the energy (*a*) to initiate fracture and (*b*) to propagate the fracture to completion. There is a correlation between the mode of fracture and energy for (*b*) which is roughly proportional to the percentage of shear in the fracture.

The transition temperature can be readily ascertained either by the measurement of the energy required to propagate tearing or by using the percentage of fracture in the shear as a basis in evaluating the change from ductile to brittle fracture. In tests on five steels, good correlation has been obtained with tests on internally notched plates 72 in wide.—J. P. S.

Cleavage Fracture of Ship Plates as Influenced by Size Effect. W. H. Wilson, R. A. Hechtman, and W. H. Bruckner. (Welding Journal 1948, vol. 27, Apr., pp. 200-s–207-s). Tests of ¾-in plate in widths of 72, 48, 24, and 12 in with a jeweller's saw-cut type of stress raiser one quarter of the width, have led to the following conclusions : (1) The average strength decreased with an increase in the width of the plate ; (2) the strength of the plates increased somewhat with an increase in the portion of the fracture that was of a shear type ; (3) the average strength of killed steels exceeds that of rimmed steels ; (4) the type of fracture, shear or cleavage, gives a reliable indication of the energy-absorbing capacity of plates ; and (5) that punched holes and sheared edges are severe stress raisers, causing a cleavage type of fracture with some reduction in strength and a great reduction in energy absorption.—J. P. S.

Relaxation Methods Applied to Engineering Problems. XIII—The Flexure and Extension of Perforated Elastic Plates. R. V. Southwell. (Proceedings of the Royal Society, Series A, 1948, vol. 193, May 27, pp. 147–171). The theory given in Part VIIA (1941) for a flat plate having a single external boundary is here extended to allow for internal boundaries (holes) at which, as well as at the external boundary, either tractions or displacements may be specified. Such holes entail appreciable complications, more especially when boundary tractions are specified and do not form an equilibrating system at each hole severally : " orthodox " studies (*e.g.*, by Bickley, Green, Howland, Jeffery) have been restricted to simple shapes (*e.g.*, one or more circular holes and plate having infinite extension). But any shape can be treated by relaxation methods, without excessive labour and with all the accuracy that has practical value. A worked example (stresses in a loaded tie-bar) shows that holes may entail a cyclic form for Airy's stress-formation χ.

Dilatometric Investigations of the Intermediate Stages of the Transformation of Austenite in Low Carbon Steels and Their Strength Properties after Intermediate-Quench Heat-Treatment. A. Pomp and E. Rolf. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung : [Abridged]. Stahl und Eisen, 1948, vol. 68, May 20, p. 203). The transformation of austenite during the isothermal heat-treatment of large specimens of a manganese and a chromium–vanadium steel was studied with a dilatometer. This enabled the strength ranges to be determined for which the isothermal treatment was superior to ordinary heat-treatment from the point of view of toughness of the product. The maximum dimensions of these steels to which the former heat-treatment could be applied were also ascertained.—R. A. R.

The Bend Test for Hardened High Speed Steel. A. H. Grobe and G. A. Roberts. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 534–490). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 540.

The Dependency of the Elastic Modulus of Pure Metals on Temperature. W. Köster. (Zeitschrift für Metallkunde, 1948, vol. 39, Jan., pp. 1–9). The elastic moduli of 32 pure metals over the temperature range −180° C. to the melting point, or up to about 1000° C., were ascertained by determining the natural frequency of transversely vibrating specimens. For iron the modulus diminishes in a straight line until 400° C. is reached ; the fall is then more rapid up to the Curie point, after which the drop is not quite so steep up to the $\alpha \rightarrow \gamma$ transformation when there is a sharp rise. In the paramagnetic range the moduli of α-iron and γ-iron decrease in a straight line with temperature.—R. A. R.

Calculation of the Moment of Torsion Failure by Use of a Diagram of True Stresses. M. P. Markovets. (Zavodskaya Laboratoriya, 1947, vol. 13, Dec., pp. 1476–1481). [In Russian].

Contribution to the Study of Mechanical Hysteresis and Fatigue. X. Waché. (Métaux, Corrosion, Usure, 1944, vol. 19, July–Aug., pp. 79–82). The results are presented of experiments, using a Coulomb micro-pendulum apparatus and an alternating torsion-testing micromachine, to study the influence of machining on internal friction. The tests were made on steels of varying carbon content and a nickel–chromium–molybdenum steel. Further tests were made after the specimens had been annealed at 800° C. in a vacuum.—J. C. R.

Some New Aspects of the Fatigue of Metals Brought out by Brittle Transition Temperature Tests. C. W. MacGregor and N. Grossman. (Welding Journal, 1948, vol. 27, Mar., pp. 132-s–142-s). Notched fatigue specimens were fractured at a range of temperatures in a slow bend-testing machine after subjection to various numbers of cycles of stress at several levels. The brittle-transition temperature was raised and the brittle fracture strength decreased with the number of cycles at given stresses both above and below the endurance limit. The tentative conclusion is that strain-hardening and ageing during the fatigue test are responsible.—J. P. S.

The Effect of Variation in Notch Severity on the Transition Temperature of Ship Plate Steel in the Notched Bar Impact Test. R. S. Zeno and J. R. Low, jun. (Welding Journal, 1948, vol. 27, Mar., pp. 145-s–147-s). Impact tests were performed at −190° C., −177° C. to −90° C., −65° C. to 0° C. and 0° to 80° C. on two types of semi-killed steel, one containing C 0·17%, Mn 0·75%, P 0·017%, S 0·035%, and Si 0·044%, the other containing C 0·23%, Mn 0·44%, P 0·015%, S 0·035%, and Si 0·06%, respectively. The specimens were (*a*) unnotched single-width standard Charpy impact specimens, (*b*) unnotched double-width specimens, (*c*) specimens with standard keyhole notch, (*d*) specimens with standard **V**-notch, or (*e*) specimens with standard **U**-notch at the root of which a fatigue crack had been produced. It is found that over this range of notch severity, the transition temperature is raised about 170° C., that the difference between the two steels is 15° C. to 30° C. the higher carbon steel having the higher transition temperature, for all degrees of notch severity, and that the standard **V**-notch Charpy specimen approaches closely the most severe conditions of loading which may be imposed on the standard impact bar. J. P. S.

The Interpretation of Notched Bar Tests—Experimental Section. (British Engine, Boiler and Electrical Insurance Co., Ltd., Technical Report for 1938, 1948, pp. 103–128). In a previous section of this article, the following conclusions have been reached: (*a*) Notched-bar tests are useful in so far as they give an indication of the energy absorbed by the material, or its capacity for deformation at a point of localized stress before the spread of a crack into the body of the specimen; (*b*) analysis of results will indicate the energy required to form the first crack, or the capacity of the material to deform without initial cracking; (*c*) if the Izod value is low, where all other properties are satisfactory, the material in question may be eliminated; equally, if the Izod value is high, it is possible to select a material with some other superior property. The present paper gives the experimental result of Izod, Charpy and slow-bend tests on a number of carbon and alloy steels and a few cast irons, variations in heat-treatment, cold work, and size, shape and direction of notch, being introduced.—J. P. S.

Influence of the Location of Longitudinal Cracks on the Impact Strength of Tempered Spring Steel. G. I. Pogodin-Alekseev. (Zavodskaya Laboratoriya, 1947, vol. 13, Dec., p. 1500). [In Russian].

Difference of Stress in Similar Parts, According to the Material. (British Engine, Boiler and Electrical Insurance Co., Ltd., Technical Report for 1938, 1948, pp. 93–102). It is not always appreciated that equal loads do not, in similarly shaped parts, always give equal stress. This article deals with the differences produced by differences of elastic modulus and of yield point, and with the effect of notches.—J. P. S.

A New Criterion of Yielding in Metals Due to Complex Stresses. K. H. Swainger. (Philosophical Magazine, 1948, Seventh Series, vol. 39, Feb., pp. 122–133). The author indicates that any plane stress system except "two-dimensional hydrostatic pressure or tension" may be reduced to a simple shear with a simple tension or compression at any point by choosing suitable directions to define the orthogonal element on which the stresses act. Any three-dimensional stress system except hydrostatic pressure or tension can be reduced to one of simple tension or compression together with two shears at any given point by a suitable choice of directions to define the element. These three stresses will define two ellipsoidal surfaces for the complete specification of yielding. If the metal is isotropic each surface is described by revolution about the normal stress axis, and then the tests with simple shear and single tension will apply on the yield criterion of the three-dimensional system.

A Theory of the Yielding and Plastic Flow of Anisotropic Metals. R. Hill. (Proceedings of the Royal Society, Series A, 1948, vol. 193, May 27, pp. 281–297). A theory is suggested which describes, on a macroscopic scale, the yielding and plastic flow of an anisotropic metal. The type of anisotropy considered is that resulting from preferred orientation. A yield criterion is postulated on general grounds which is similar in form to the Huber-Mises criterion for isotropic metals, but which contains six parameters specifying the state of anisotropy. By using von Mises' concept (1928) of a plastic potential, associated relations are then found between the stress and strain-increment tensors. The theory is applied to experiments of Körber and Hoff (1928) on the necking under uniaxial tension of thin strips cut from rolled sheet. It is shown, in full agreement with experimental data, that there are generally two, equally possible, necking directions whose orientation depends on the angle between the strip axis and the rolling direction. As a second example, pure torsion of a thin-walled cylinder is analysed. With increasing twist, anisotropy is developed. In accordance with recent observations by Swift (1947) the theory predicts changes in length of the cylinder. The theory is also applied to determine the earing positions in cups deep-drawn from rolled sheet.

Stress Distribution around a Hole Near the Edge of a Plate under Tension. R. D. Mindlin. (Proceedings of the Society for Experimental Stress Analysis, 1948, vol. 5, No. II, pp. 56–68). Mathematical theory indicates that, contrary to an earlier statement, the stress in the material between a circular hole and the edge of a semi-infinite plate is always tensile and approaches zero as the hole approaches the edge of the plate. Photo-elastic experiments with a plate not of infinite width, but of width equal to 5–6 times the diameter of the hole, confirm this theory.—J. P. S.

Development of Residual Stresses in Strip Rolling. R. McC. Baker, R. E. Ricksecker, and W. M. Baldwin, jun.

(American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2333 : Metals Technology, 1948, vol. 15, Apr.). The authors have carried out an investigation of the causes of residual stress in cold-rolled strip. They claim that these stresses, expressed as a fraction of the yield strength of the rolled strip, are proportional to the square of the ratio of the thickness of the strip to the length of the arc of contact between the strip and the roll. This relationship is independent of the size-reduction per pass, whilst the residual stresses are nearly constant across the width of the strip. The conclusions are used to explain "fire-cracking" *i.e.*, transverse cracks appearing on the over-rapid heating of stressed material, and "alligatoring," where the strip splits along a plane parallel to and midway between the rolled surfaces.—J. P. S.

Electrical Resistance Wire Strain Gauges—Their Development and Use. J. Edwards. (Metal Treatment, 1947, vol. 14, Winter Issue, pp. 213–221 ; 1948, vol. 15, Spring Issue, pp. 17–26). The paper describes an electrical method of strain measurement, based on changes in electrical resistance, which is capable of wide application. Details of the thermoplastic cements for fixing and the electrical circuits, the method of calibration, and its application for measuring static, slowly varying, and dynamic stresses are given, and the possibility of remote recording is discussed.—R. A. R.

Tests on Flow and Fracture of Welded and Unwelded Tubes of Steel. L. V. Griffis, G. K. Morikawa, and S. J. Fraenkel. (Welding Journal, 1948, vol. 27, Apr., pp. 161-s–168-s, 208-s). Tests have been made on tubular specimens 3 in in dia turned from bars of a 0·23% carbon, semikilled steel, to determine the effect on plastic flow, and on the mode of fracture, of (1) the ratio of the principal stresses, (2) the presence of welded seams, (3) annealing of (*a*) unwelded, and (*b*) welded material, and (4) temperature. Variations in the principal stresses were obtained by the application of oil pressure inside the tube. It was found that : (1) Variations in the ratio of the principal stresses from zero to infinity had no appreciable effect on the ductility ; (2) welded seams did affect it considerably, lowering it 20–50% ; (3) annealing of (*a*) unwelded material had little effect on the stress-strain relationships, the fracture strength, or the ductility, (*b*) welded material affected the ultimate strength most if performed before and after welding, less if after welding, and least if before welding ; (4) temperatures down to −90° F. increase both strength and ductility but at −100° F. the ductility falls sharply. Similar tests of 20-in tubes of identical material have been studied to determine size effects and comparisons with tensile tests have been made ; it is concluded that the ductility is not affected by a change in diameter, that the true ultimate strength differs, but that insufficient data are available for correlation, and that the ratio of true stress at failure in a tube to failure in a tensile specimen is less than unity and decreases with increasing diameter of the tube. Finally, the critical temperature for embrittlement appears to rise sharply with increasing specimen size.
J. P. S.

Extent of Peening Weld Deposits for Stress Relief. J. L. Morris. (Welding Journal, 1948, vol. 27, Mar., pp. 148-s–157-s). Peening of welds with pneumatic or electric hammers will give plastic flow of the weld metal and full stress-relief, if the energy of the hammer and shape of the tip are suitable. A small spherically shaped tool is better than a flat-ended one.—J. P. S.

Effect of Cold Stretching and Subsequent Artificial Ageing on the Strength Properties of Steel, Especially with Multi-Axial Deformation. A. Krisch and F. Straeter. (Kaiser-Wilhelm-Institut für Eisenforschung : [Abridged]. Stahl und Eisen, 1948, vol. 68, Apr. 22, p. 165). The authors have investigated the effect of cold stretching and subsequent accelerated ageing on the properties of manganese steel and chromium–nickel steel tubes with thick walls after multi-axial stressing. The yield point increased with the amount of cold stretching and the tempering temperature ; the limit of proportionality decreased after cold stretching and increased again after tempering.—R. A. R.

Ferro-Magnetic Metals. A. Borowik. (Iron and Steel, 1948, vol. 21, Jan., pp. 3–6 ; Feb., pp. 39–43 ; Mar., pp. 81–86 ; Apr., pp. 117–121). Internal stresses in metals are discussed, and magnetic-testing apparatus and methods for the identification and measurement of these stresses are described.—J. R.

On the Removal of Time Stresses in Three-Dimensional Photoelasticity. M. M. Frocht. (Proceedings of the Society for Experimental Stress Analysis, 1948, vol. 5, No. II, pp. 9–13). Bakelite models free from external loads often develop internal stresses ; these, known as "time-stresses" arise from the absorption of moisture from the air, being compressive on the outer surface and tensile in the interior. These stresses can be removed either by simply waiting for the natural rearrangement of stresses as equilibrium humidity is reached or by removal of the skin to a suitable depth, which assists the process materially.—J. P. S.

Equivalence of Photoelastic Scattering Patterns and Membrane Contours for Torsion. D. C. Drucker and M. M. Frocht. (Proceedings of the Society for Experimental Stress Analysis, 1948, vol. 5, No. II, pp. 34–41). A simple theoretical derivation supported by experiment is presented to show that photoelastic scattering patterns can be obtained which are in every way the same as membrane contours for pure, St. Venant, torsion. A sheet of parallel rays of polarized light is sent along a shaft and the scattered fringe pattern observed from a perpendicular position. The fringes produced are lines of constant membrane elevation, or of constant value of the torsion stress function, and for a given cross-section the difference in elevation from one fringe to the next is a constant depending upon the twisting moment and material constants only.—J. P. S.

Three-Dimensional Photoelastic Analysis by Scattered Light. E. M. Saleme. (Proceedings of the Society for Experimental Stress Analysis, 1948, vol. 5, No. II, pp. 49–55). The scattering of polarized light is observed in directions normal to the plane of transmission, and analysed with a microphotometer. It is suggested that this method presents definite advantages for analysing the torsion of beams.—J. P. S.

The Electrical Resistance Strain Gauge S.R.-4. H. Dührkop. (Dansk Teknisk Tidsskrift, 1948, vol. 72, Jan., pp. 5–6). [In Danish].

Strain Gauges. C. H. Gibbons. (Metalen, 1948, vol. 2, May ; pp. 187–193). [In Dutch]. The principles and construction of the SR-4 electrical resistance strain gauge are described.—R. A. R.

The Development and Application of Electrical Strain Measurers for Determining Static and Dynamic Stresses. A. R. Anderson. (Schweizer Archiv, 1947, vol. 13, Nov., pp. 321–336). A detailed description is given of the SR-4 electrical-resistance strain gauge with circuit diagrams for the determination of static and dynamic stresses. Examples of its application are described.
R. A. R.

How to Organise for Experimental Stress Analysis. (Product Engineering, 1948, vol. 19, Apr., pp. 114–136). The apparatus for dealing with a variety of stress-analysis problems is described, it includes brittle coating, and

photoelastic methods, and the use of electrical and mechanical strain gauges.—J. P. S.

Causes of Cleavage Fracture in Ship Plate—Tests of Wide Notched Plates. A. Boodberg, H. E. Davis, E. R. Parker, and G. E. Troxell. (Welding Journal, 1948, vol. 27, Apr., pp. 186–s-199-s). Tests were performed on notched plates from 3 to 108 in wide of three lots of semi-killed steel, one nickel alloy steel, one fully killed steel, and one quenched and tempered steel. For all specimens the maximum load, the load at the formation of the first crack, the load at failure, the energy absorption to maximum load, the mode of fracture, the reduction in area and the strain distribution were measured. It was found possible to produce brittle cleavage fractures similar to those found in ship plate fractures in service. Different tests arranged the steels in approximately the same order, as regards relative brittleness, but did not give the same transition temperatures; these may, in ordinary commercial steels, range from below freezing to well above room temperatures, and are affected by composition, microstructure, and notch geometry.—J. P. S.

Research Work on Rail Sections. W. Leaf. (Transactions of the American Society of Mechanical Engineers, 1948, vol. 70, Jan., pp. 31–35). A horizontal fatigue crack occurred in the upper part of the web of a 112-lb flat-bottomed rail. This was due to faulty design of the section. The photoelastic investigation of rail stresses and the improved design which was developed are described.—R. A. R.

Progress Reports of Investigations of Railroad Rail and Joint Bars. R. E. Cramer, N. J. Alleman, and R. S. Jensen. (University of Illinois, 1947, Engineering Experiment Station Reprint Series No. 37). This covers progress reports on (*a*) investigation of failures of railroad rails, where the indications are that controlled cooling has eliminated most of the causes of failure, though some still result from porosity produced by overheating before rolling; (*b*) corrugated rails, which condition appears to result from hard spots produced by wheel slip; (*c*) rolling-load tests of joint bars, where fatigue life for a given wheel load is found to increase in proportion to the section modulus; (*d*) fatigue tests of rail webs, where the effects of moisture acidified by smoke are being studied; and (*e*) shelly rails where it has been established that low-alloy steels are less susceptible to this type of failure than carbon steels.—J. P. S.

Allowable Stresses for Steel Members of Finite Life. G. C. Noll and M. A. Erickson. (Proceedings of the Society for Experimental Stress Analysis, 1948, vol. 5, No. II, pp. 132–143). Diagrams are produced which present data on permissible stresses in a convenient form for easy reference in the solution of structural problems of fatigue; the lines are plotted in conformity with the exponential law for 1000 to 1,000,000 cycles; the parameters involved are Brinell hardness, over a range of 160–555, and surface condition (ground, machined hot rolled, or as forged).—J. P. S.

Dynamic Capacity of Rolling Bearings. G. Lundberg and A. Palmgren. (Ingeniörsvetenskapsakademiens Handlingar, 1947, No. 196: Acta Polytechnica, 1947, No. 7). The classical theory of strength cannot satisfactorily explain fatigue of materials at intense stress concentrations. The authors lay a foundation for statistical theory of fatigue, considering the dispersion in strength of material and the dependence of the strength of a volume element on the depth below the surface. From this a general theory is developed for the dynamic capacity of different types of roller bearings, and for equivalent radial and thrust loads under different loading and running conditions. The theory was in agreement with tests at the SKF works.—R. A. R.

Flexural Fatigue Strength of Steel Beams. W. M. Wilson. (University of Illinois, 1948, Engineering Experiment Station Bulletin No. 377). Stringers and short beams in bridges are particularly liable to fatigue failure as they have to endure a high ratio of maximum to minimum load, a large number of stress-cycles during the life of the structure and, by their construction, usually incorporate severe stress raisers in the tension flange. Flexural fatigue tests, of rolled beams with various types of reinforcement, *e.g.*, cover-plates, lateral plates, and stiffeners, some riveted on, some welded with either continuous or intermittent fillet welds, and of some beams completely fabricated from plate, were carried out, and the fatigue strengths corresponding to failure at 100,000 and 2,000,000 reversals, of stress varying from near zero to a maximum were determined by extrapolation.

The conclusions are that: (1) There is a very large reduction in fatigue strength caused by the abrupt change in section at the end of a partial-length cover-plate; (2) beams with full-length cover-plates continuously fillet-welded, and beams fabricated by connecting flange plates to cover-plates by continuous fillet welds have a lower fatigue strength than beams as rolled; (3) beams with full-length cover-plates intermittently welded have a lower fatigue strength than those continuously welded; (4) the reduction in fatigue strength caused by intermediate stiffeners depends on the portion of the beam to which the stiffeners are welded, being least when they are welded only to the compression flange and the compression portion of the web; (5) beams with welded partial-length cover-plates with ends tapered by reducing the thickness had greater fatigue strength than those where there was no taper or the taper was made by reducing the width; (6) where full-length cover-plates were attached by riveting, the fatigue strength was less than where they were attached by continuous fillet welds; however, where partial length cover-plates were attached by riveting, the fatigue strength was as great as, or slightly greater than, where they were attached by welding; (7) the effect of lateral plates, whether attached by transverse or by longitudinal welding, or by riveting was to reduce fatigue strength—no more, however, than was done by any of the methods of attaching partial-length cover-plates.—J. P. S.

The Fatigue Strength of Binary Ferrites. E. Epremian and E. F. Nippes. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 870–896). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 539.

Fatigue Characteristics of Rotating-Beam *Versus* Rectangular Cantilever Specimens of Steel and Aluminium Alloys. F. B. Fuller and T. T. Oberg. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 665–676). Fatigue tests were conducted in Krouse vibratory non-rotating cantilever beam (fixed deflection) and R. R. Moore rotating simple beam (constant load) fatigue-testing machines to compare the fatigue characteristics in reversed bending for material tested in these machines in the form of round rotating simple beam and of rectangular cantilever beam specimens. Specimens were machined from extruded aluminium alloys and from chromium–molybdenum flat steel plate of several degrees of hardness. The fatigue characteristics in general for the material in the form of rectangular specimens were consistently lower than those for the material in the form of round specimens.

Rate of Propagation of Fatigue Cracks in 12-Inch by ¾-Inch Steel Plates with Severe Geometrical Stress Raisers. W. M. Wilson and J. L. Burke. (University of

Illinois, 1947, Engineering Experiment Station Bulletin No. 371). Fatigue tests were carried out on (*a*) a rimmed steel as rolled, (*b*) the same after straining 1% and rolling 2 hr at 212° F., and (*c*) a normalized killed steel. The specimens were 2 ft × 1 ft × $\frac{3}{4}$-in plate with the middle half reduced to 11$\frac{1}{2}$ in wide. The stress raiser consisted of a $\frac{3}{8}$-in hole at the geometric centre of the wide face, extended 1 in transversely each way with a hacksaw cut 0·035 in and a further $\frac{1}{8}$ in with a jeweller's hacksaw cut 0·011 in wide. Stress of ± 16,000 lb/sq in. was applied at 180 cycles/min and tests were carried out on (*a*) and (*b*) above, at 120° F., 80° F., 32° F., and 0° F.; on (*c*) at 80° F., 32° F., 0° F., and − 40° F. with Charpy impact tests to correspond.

The jeweller's hacksaw cut is found to be as severe a stress raiser as a fatigue crack would be, and the number of cycles to produce a crack of average length 0·60 in was used as an index of the rate of propagation. It is found that there is no close relation between this rate and the Charpy impact figure. It is therefore suggested that the notch-sensitivities indicated by the two methods are two quite different properties.—J. P. S.

Experiments on the Elastic Homogeneity of Metals. C. Sălceanu and M. Borneas. (Comptes Rendus, 1948, vol. 226, May 3, pp. 1422–1424). The authors have investigated the influence of tension on the oscillation period of a torsional pendulum and noted the variations of this period. The apparatus used is described, and the results obtained with steel, iron, silver, aluminium, and copper wires are presented.—J. C. R.

Structural Defects and Mechanical Properties of Metals. Contribution to the Study of the Mosaic Structure. C. Crussard. (Métaux, Corrosion, Usure, 1944, vol. 19, May–June, pp. 55–66). A review is given of the present state of knowledge on defects in the structure of metals and their relationship to mechanical properties, and on the mosaic structure, with numerous references to the work of various investigators on this subject. It is emphasized that the fundamental laws governing the occurrence of defects due to crystallization or recrystallization are of a statistical nature.—J. C. R.

Explains Steel Hardenability. W. E. Jominy. (S.A.E. Journal, 1948, vol. 56, Apr., pp. 40–48, 58). The principles by which data on the physical and mechanical properties of steels may be used in selecting a steel for a given purpose are explained, with particular reference to martensitic steels.—M. A. V.

Carbon and Alloy Steels. T. L. H. Butterfield. (Welding, 1948, vol. 16, Jan., pp. 15–22; Feb., pp. 61–66; Mar., pp. 113–120; Apr., pp. 152–156, 162). In the first part of this series of articles the iron-carbon diagram is explained and used to describe the effects of slow and rapid cooling on carbon and alloy steels. In the second part the factors affecting weldability, and the tests for assessing weldability are dealt with. In the third part the relationship between hardenability and hardness is discussed and the results of weldability and hardness tests on 37 high-tensile chromium–molybdenum and nickel–chromium–molybdenum steels are presented and compared with test data from the Battelle Memorial Institute. Nickel–chromium–molybdenum steels (Ni 3$\frac{1}{2}$%) had better weldability than chromium-molybdenum steels (Cr 1$\frac{1}{2}$%) of equal carbon content. For a given carbon content, basic electric-furnace steels showed decidedly better weldability than basic open-hearth steels. Acid open-hearth steels were of intermediate weldability. The literature on weldability of alloy steels is reviewed in the fourth part with particular reference to the relationship between weldability and hardenability, hot and cold cracking, the hydrogen inclusion theory, and the development of electrodes to overcome cracking difficulties. It is concluded that, although more alloy steels may now be welded, with a suitable choice of electrode and technique, there is still a need for much further research.—R. A. R.

The Microhardness of Metals and Minerals. Emma M. Onitsch. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1948, vol. 93, Jan.–Mar., pp. 7–12). The principles of macro- and microhardness testing and methods of evaluating the readings are explained. Many determinations on metals and minerals show that the value of the exponent n in the equation $P = ad^n$ (where P is the load, and d the diameter of the impression) is closely related to the absolute hardness of the material. The harder the material the smaller is the value of n. The softer the material the nearer n approaches 2. The hardness-testing of minerals and the relation between microhardness and Moh hardness are also dealt with.—R. A. R.

Microhardness Testing. H. Dinner. (Sulzer Technical Review, 1947, No. 3–4, pp. 6–10). The Zeiss Diritest apparatus has proved unsatisfactory to operate owing to the difficulty of centring the impression on the optical axis of the microscope and Haremann has devised a new tester. In this instrument the diamond pyramid is located in the front lens of the objective. The diamond pyramid has a diagonal of 0·8 mm., and a sufficient annular area of the lens is left for lighting and photographing the object. A device is built in for generating and measuring the test load. The technique of measurement is described in detail with examples illustrated by photomicrographs.—M. A. V.

Hardness and Brittleness in Hardened Mild Carbon Steel. B. D. Enlund. (Jernkontorets Annaler, 1948, vol. 132, No. 4, pp. 91–104). [In Swedish]. An investigation of the brittleness of mild steels with up to 0·20% of carbon after hardening at different temperatures is described. They became very brittle after quenching from a comparatively low temperature, but were tougher and more ductile after quenching from a higher temperature. Hence, the greatest brittleness in welds is not found close to the weld where the hardness is at the maximum, but further away where the steel has been heated to 1350–1475° F., provided that the steel in this zone has been rapidly cooled.

A Simplified Warm Hardness Test for Temperatures below 700° F. A. L. Pranses. (Instruments, 1947, vol. 20, Nov., pp. 1006, 1066: [Abstract]. Bulletin of the British Scientific Instruments Research Association, 1948, vol. 3, Apr., p. 113). A modification of the Rockwell "B" hardness test is described for use with steels at temperatures between room temperature and the lower critical ("warm" refers to sub-critical temperatures for steels).

Measurement of Hardness by Height of Rebound. G. Joly. (Fonderie, 1946, Dec., pp. 419–420). A note is presented on the Vallaroche scleroscope, which is based on the same principle as the Shore scleroscope, and is intended to measure hardness by the height of the rebound. A table is presented showing how results obtained by both types of scleroscope and Rockwell B and C and Vickers h/10 tests correspond. The author is not satisfied that the Vallaroche scleroscope provides an accurate and reliable measurement of hardness.—J. C. R.

The Determination in America of the Brittle-Fracture Sensitivity by Means of Notched Specimens. R. P. Steyn. (Lastechniek, 1948, vol. 14, June, pp. 67–71). [In Dutch].

Temper Hardening of Carbon Steel. K. F. Strarodubov. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'U.R.S.S., 1946, vol. 53, pp. 213–215: British Abstracts, 1948, Section B1, Feb., col. 78). When the mechanical

and physical properties of steel are plotted against tempering temperatures of 400–600° C. the graphs deviate considerably from smooth curves. This is ascribed to transformation of carbides of intermediate composition into cementite.

Effect of Particle Size on the Wear of Ball-Mill Balls. S. Mörtsell. (Jerkontorets Annaler, 1948, vol. 132, No. 4, pp. 112–114). [In Swedish]. Grinding tests were made using 75 steel balls 25·5–26·5 mm in dia on a charge of 1608 g of quartz with a mean particle size of 0·078 mm, and turning the mill at 67·6 r.p.m. The loss of weight of the balls and the mean particle size of the quartz were determined after successive 1-hr periods. The wear per unit of time increased rapidly at first and then slowly decreased with decreasing mean particle size. This indicates that increasing the efficiency of separating the fines, so that fines under say 200 mesh are effectively excluded from the returns to the mill, will reduce the wear of the balls of a mill working in a closed circuit with a classifier or screen. R. A. R.

Wear Tests on Grinding Balls. T. E. Norman and C. M. Loeb, jun. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 2319: Metals Technology, 1948, vol. 15, Apr.). Test balls, distinctively marked, were charged into a commercial mill along with its regular contents; those recovered, considered to represent the whole, were weighed and examined. It is considered that wear is in direct proportion to surface area. The best wear resistance is given by a matrix of martensite or low-temperature bainite, plus retained austenite, whilst spheroidized carbides enhance it further. The effect of alloying elements in the steel is to retard austenite decomposition at subcritical temperatures, and therefore choice of composition depends on their ability, under heat-treatment, to promote the desired structure.—J. P. S.

Wear Resistance of Gray Iron Diesel Engine Liners. T. E. Eagan. (Foundry, 1948, vol. 76, May, pp. 134–138, 308–310, 312). Service conditions for Diesel engine cylinder liners may include dusty atmospheres, corrosive fuels, marine conditions, and varying load requirements. A large number of liners of various types of grey cast iron have been examined. It is suggested that the best structure for all-round use is that of random graphite flakes in a pearlitic matrix such as would be obtained with the composition nickel 1·0–1·5%, chromium 0·30–0·40%, and molybdenum 0·25–0·35%.—J. P. S.

Friction and Wear of Metals in the Presence of Liquid Gases. P. I. Riumin and Yu. N. Riabinin. (Kislorod, 1946, No. 4, pp. 35–41: [Abstract]. Engineers' Digest (London), 1948, vol. 9, May, p. 146).

The Wear of Steel: Theory and Practice. R. Walzel. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1948, vol. 93, Jan.–Mar., pp. 28–33). After discussing the theory of wear and showing the correlation of the factors affecting it, the results of two series of tests with rails are described. In one, the rates of wear of two rails forming a single track in the wet section of an Austrian tunnel are compared; a copper-bearing steel rail (Cu 0·25%) showed much less wear than a rail containing no copper. In the second, the wear on two curved tracks (radius 250 m) one laid with 44·35 kg/m rails and the other with 48·89 kg/m rails are compared. The heavier and stiffer rails showed greater wear on both top and side.—R. A. R.

Irreversible Electrode Potentials of Metals and Their Solid Solutions. Part I.—Irreversible Electrode Potentials of Metals. Part II.—Electrode Potentials of Solid Solutions. G. W. Akimov and G. B. Clark. (Transactions of the Faraday Society, 1947, vol. 43, Nov.–Dec., pp. 679–684, 685–697). A method of measuring the electrode potentials of metals and alloys while the submerged surface of the test-piece is rubbed is described. Comparison of the potentials recorded with and without rubbing permitted conclusions to be drawn as to the tendency of the material to form a protective film. Twenty-two metals, including aluminium, silicon, chromium, molybdenum, manganese, iron, cobalt, nickel, copper, zinc, cadmium, and tin and twenty-three non-ferrous alloys were examined. For pure metals the tendency to film formation decreases from left to right across the Periodic Table. Changes in the electrode potential caused by rubbing the surface are similar for metals in the same group of the Periodic Table. The action of irreversible potentials of metals and alloys is discussed.—A. E. C.

Temperature *versus* Permeability in Nickel–Iron Alloys. L. C. Hicks. (Steel Horizons, 1948, vol. 10, No. 1, pp. 16–17: Chemical Abstracts, 1948, vol. 42, May 10, col. 2910–2911). The need for special electronic equipment in military equipments resulted in a greatly increased use of high-permeability nickel–iron alloys for magnetic cores. Magnetization data are presented for nickel–iron alloy ring samples made from the following alloys: Mumetal (Ni 76·5%, Cr 1·35%, Cu 4·40%), 4750 (Ni 48·5%), Monimax (Ni 46·8%, Mo 3·19%), and Sinimax (Ni 42·7%, Si 3·23%).

A Mechanism of Magnetic Hysteresis in Heterogeneous Alloys. E. C. Stoner and E. P. Wohlfarth. (Philosophical Transactions of the Royal Society of London, Series A, 1948, vol. 240, May 4, pp. 599–644). To account for the high coercivities of permanent magnet alloys, it is suggested that they contain "particles" distinct in magnetic character from the general matrix, for which domain boundary formation is energetically possible, and that for these particles, change of magnetization takes place only by rotation of the magnetization vector. The resolved magnetization may change discontinuously at critical values of the field. The character of the magnetization curves depends on the magnetic anisotropy of the particle and the orientation of "easy axes." Anisotropy may result from shape, magneto-crystalline effects, and strain, and these three effects are analysed quantitatively. With the more favourable orientation, the maximum coercivities for iron due to magneto-crystalline and strain effects are about 400 and 600 respectively; greater coercivities may be due to shape, and for prolate spheroids of dimensional ratio 10 the coercivity would be 10,000. The critical equatorial diameter of a prolate spheroid, below which boundary formation cannot occur varies from $1·5–6·1 \times 10^{-6}$ cm and $6·2–25 \times 10^{-6}$ cm for iron and nickel respectively as the dimensional ratio varies from 1 to 10. The application of these results to non-ferromagnetic metals containing ferromagnetic impurities, powder magnets, and high coercivity alloys of the dispersion-hardening type is discussed, and in the latter case, the positive bearing on the effects of cooling in a magnetic field is indicated.—M. A. V.

The Progress of Failure in Metals as Traced by Changes in Magnetic and Electrical Properties. P. E. Cavanagh. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 639–650). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 304.

A New Type of Magnetic Flaw Detector. C. H. Hastings. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 651–664). *See* Journ I. and S.I., 1947, vol. 157, Oct., p. 305.

The Interpretation of the Influence of a Magnetic Field on the Internal Friction of Ferromagnetic Bodies. C. Boulanger. (Comptes Rendus, 1948, vol. 226, Apr. 26,

pp. 1341–1343). The internal friction of steels, austenitic alloys, and other metals was measured by observing the decrement (δ) of oscillation of wires of the various metals in a Coulomb micropendulum. When plotted against the amplitude, the curves showed a pronounced maximum value of δ. The effect of superposing magnetic fields of progressively increasing intensity was to make the maximum less marked, until it finally disappeared. At the same time it was displaced at first towards the δ-axis, and then away from it. It is suggested that the phenomenon is applicable by the Weiss theory of molecular fields, on the grounds that an elastic deformation, resulting in a rotation of these fields, is equivalent to the superposition of a magnetic field. An analogy is drawn between mechanical and magnetic hysteresis, the loss in energy per cycle being proportional to the cube of the amplitude, in accordance with a law analogous to Rayleigh's law. It also follows that at saturation the molecular fields cannot be further displaced, and the decrement-amplitude curve becomes similar to that of a non-ferromagnetic body. Work-hardening will affect the shape of the curves; and the phenomena described apply only to magnetically soft metals and not, for example, to quenched steels.—M. A. V.

Plastic Replicas for Surface-Finish Measurement. J. Pearson and M. R. Hopkins. (Journal of The Iron and Steel Institute, 1948, vol. 159, May, pp. 67–72).

The Measurement of the Damping Capacity of Metals in Torsional Vibration. G. A. Cottell, K. M. Entwistle, and F. C. Thompson. (Journal of the Institute of Metals, 1948, vol. 74, Mar., pp. 373–424). The cause of the discrepancy between the results of "mechanical" and "physical" methods of measuring damping capacity in torsional vibration has been investigated. It has been found that in the case of a machine of the Föppl-Pertz type, as hitherto constructed, the energy loss in the machine itself may, when testing a material of low damping capacity such as Duralumin, amount to about 500 or more times the intrinsic energy dissipation of the specimens. All the major sources of loss have been isolated, and complete re-design of an existing machine has reduced the measured damping to the order of twice the lowest values measured by the physical method. The use of a solid of revolution in place of the usual rectangular bar as the oscillating inertia has been found to be essential. The air-friction energy loss over the surface of the oscillating wheel was measured in order to determine the air-loss correction to be applied to the test results. This latter work necessitated the construction of a small machine for tests at reduced air pressures. The damping capacity of Duralumin as measured with this machine was found to be in excellent agreement with the lowest determinations by physical methods. This investigation confirms that the physical and mechanical methods are in fact measuring the same property, and shows that, at any rate for aluminium alloys, results of the same order can be obtained by the two methods, provided that the apparatus is designed correctly.

The Estimation of Specific Damping Capacity from Measurements of Experimental Decay Curves. G. L. J. Bailey. (Journal of the Institute of Metals, 1948, vol. 74, Mar., pp. 417–424). In an appendix to the paper by Cottell, Entwistle, and Thompson (*see* preceding abstract) a method of treating experimentally recorded decay curves is proposed which permits the estimation of the specific damping capacity at any measured amplitude, within calculable limits of error.

The Chemical Activity of Metal Surfaces as Influenced by Various Conditions of the Metal. J. A. Hedvall. (Chalmers Tekn. Högskola, Gothenburg, Harald Nordenson, 60 år, 1946, pp. 165–176: Chemical Abstracts, 1947, vol. 41, Apr. 10, col. 1948). Examples are presented to illustrate the principle that in transitional states, solid substances obtain a relative maximum of activity. In Curie transitions of metallic and non-metallic ferromagnetic substances the catalytic effect increases. The tarnishing velocity of metal is accelerated by supersonic vibrations.

A Survey of Applications of an Electronic Inspection Instrument. (Engineering Inspection, 1948, vol. 12, Spring Issue, pp. 6–12). Applications of the Cornelius Electronic Comparator are described. This is a standard electronic instrument capable of rapidly carrying out all the usual inspection tests required in modern engineering practice as well as many unusual tests. The examples include: (*a*) Sorting mixed batches of components; (*b*) checking the thickness of anodic coatings on turbine blades; (*c*) measuring tube-wall thickness; and (*d*) comparing dimensions.—R. A. R.

The Use of Ultrasonics for the Study of Defects in Materials. G. A. Homes. (Prévention des Accidents et Contrôles Techniques, 1947, vol. 1, June, pp. 55–57; Aug., pp. 126–129). The principles of ultrasonic investigation of metals are outlined and the Ateliers de Constructions Electriques de Charleroi—Association des Industriels de Belgique (known as "A.C.E.-A.I.B.") apparatus is described. The results obtained with it are broadly stated.—R. F. F.

X-Ray Thickness Gauge for Cold-Rolled Strip Steel. W. N. Lundahl. (Electrical Engineering, 1948, vol. 67, Apr., pp. 349–353). The gauge described operates by measuring the intensity of transmitted radiation. Two X-ray generators are used; the radiations, after passing respectively through the strip under test and a standard sample, fall on an electron multiplier surrounded by a fluorescent screen. The two generators are activated 180° out of phase by pulses produced from alternate half-cycles of the supply. The current from the electron multiplier is amplified, resolved into its two components, and the difference between these measured to give a direct thickness indication. Complete circuit details, including the stabilizer circuits, are given.—M. A. V.

X-Ray Data on the Mosaic Structure of Metal Crystals. A. Guinier. (Métaux, Corrosion, Usure, 1944, vol. 19, May–June, pp. 66–70). An account is given of data that can be deduced from X-ray diffraction studies of the structure of metal crystals, but it is considered that the use of X-rays in studying the mosaic structure is rather restricted.—J. C. R.

Source of Sulphur Entering Steel Disclosed by Radio-active Tracers. (Steel, 1948, vol. 122, Apr. 26, p. 112). By the addition of artificial pyrites made with radio-active sulphur to a coke-oven charge it has been found that both the pyritic sulphur and the organic sulphur in coal are carried over equally to the coke, so that there is no advantage in using a low-pyritic-sulphur coal.

The application of radio-active phosphorus in the Bessemer converter would, it is suggested, enable the use of automatic controls to turn down and shut off the vessel when the process was completed.

Radio-active tracers are not expensive, but care should be taken in experiments to use the minimum amounts, to provide adequate shielding and health precautions, and to dispose of the waste safely.—J. P. S.

The Contraction of Metal. H. T. Angus. (Machinery Lloyd, 1948, Jan., No. 1A, pp. 48–56: [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Apr., p. 19). An account is given of the contraction of metal that occurs in the liquid state, during solidification, and in the solid state. The mechanism of cooling and the use of chills are discussed.

Progress in Stainless and Heat Resisting Steels. L. Sanderson. (Steam Engineer, 1948, vol. 17, Mar., pp. 305–307). This is a review of minor technical developments in the field of stainless steel; the author refers briefly to the use of hydrogenated castor oil as a drawing lubricant, the "infiltration" technique in powder metallurgy, "powder-cutting," sodium hydride descaling, and beryllium-cementation. In addition he deals with work in progress on very highly alloyed nickel–chromium cast irons.—J. P. S.

Creep and Creep-Rupture Testing. G. V. Smith, W. G. Benz, and R. F. Miller. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 615–638). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 538.

Graphitization of Steel at Elevated Temperatures. A. B. Wilder and J. D. Tyson. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 233–262). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 538.

Mechanical Properties of Metals at Low Temperatures: A Survey. L. Seigle and R. M. Brick. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 813–869). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 539.

The Use of "Stainless" Steel for Steam Turbine Blades. C. Wilwertz. (Revue Technique Luxembourgeoise, 1948, vol. 40, Apr.–June, pp. 80–82). Serious defects in medium- and low-pressure steam turbines have occurred when 13% chromium steel was used for the blades. These defects are due to the poor welding properties of this steel and two specific cases of defects are described to illustrate this point. In the first case reinforcing steel wires of the same composition were brazed to the 13% chromium steel blades using a 25% silver solder (melting point 760° C.). In the defective turbine the blades were broken, near the wire welds, and the reinforcing wires in many cases were also broken. Micrographic examination of the defective blades showed an increase in grain size due to the heat of welding, and the Vickers hardness was 380 to 560 for the superheated metal as compared with 200 to 220 for the sound metal. The dilatation curve taken during the heating of a blade to 1000° C. and cooling shows Ac_3 to be about 820° C. In the second case the blades were brazed using a 45% silver solder (melting point 725° C.) and special gas burners, but the turbine developed defects similar to the first case. Means of preventing these defects are discussed, including the use of brazing metal with a melting point below 500° C.—R. F. F.

The High-Temperature Fatigue Strength of Several Gas Turbine Alloys. P. R. Toolin and N. L. Mochel. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 677–694). The results of fatigue tests at 1200° and 1500° F. on proposed alloys for gas turbines are reported. The compositions tested included 18/8 stainless steels and many chromium–nickel alloys containing other alloying elements. Both wrought and precision-cast forms of material were tested. The wrought form generally had a higher fatigue strength than the cast form. The Westinghouse machine used for testing is described.—R. A. R.

Contribution to the Study of Heat Resistance of Austenitic Steels. Influence of Treatments and Structure. E. Morlet. (Métaux, Corrosion, Usure, 1944, vol. 19, Jan., pp. 1–9). When studying the high-temperature properties of heat-resistant austenitic steels for gas turbines, a considerable variation in the creep rate of test-pieces of the same composition and even from the same cast, was noticed. Comparison of the microstructure of specimens after a hot tensile test indicated that grain growth was an important factor in creep resistance and could explain the variation noted. The influence of stabilizing heat-treatments, the effects of cold straining after heat-treatment, and the influence of structure on time-elongation curves over a long period, were studied. The appliances used and the tests made are described and the results obtained are discussed. The following conclusions are reached: (*a*) To limit scatter of results, heat-treatments must be carried out at exactly the same temperatures; (*b*) coarse-grained steels are generally more heat-resistant than fine-grained steels; (*c*) scatter was more pronounced with long-term tests; these tests indicated that forged coarse-grained steels were superior to superheated coarse-grained steels and fine-grained rolled steels; and (*d*) steels with a coarse grain caused by superheating were liable to intercrystalline rupture.—J. C. R.

Concept of the Hydrogen Potential in Steam-Metal Reactions. C. A. Zapffe. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 315–354). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 540.

Influence of Hydrogen on the Modulus of Elasticity of Iron. G. Chaudron and L. Moreau. (Métaux, Corrosion, Usure, 1944, vol. 19, Mar.–Apr., pp. 50–51). When the lattice of iron is charged with hydrogen by electrolysis, a considerable increase in hardness results and this is not modified when the iron is degassed by ionic bombardment. The authors have now measured the variations which occur in the modulus of elasticity during these processes. Molecular hydrogen was evolved if the test-piece was plunged into boiling water and the value of the modulus of elasticity rose, but if the test-piece was degassed by ionic bombardment the value of the modulus dropped. Hydrogen in the lattice was considered to have modified substantially the atomic linkages as it caused relatively large variations in the modulus of elasticity.—J. C. R.

Various Methods of Fixation of Hydrogen by Metals. (Rôle of the Mosaic Structure of Metal). G. Chaudron. (Société Philomathique, 25 May, 1944: Métaux, Corrosion, Usure, 1944, vol. 19, Sept.–Oct., pp. 92–93). A brief review is presented of the occurrence of hydrogen in intercrystalline spaces, in the spaces of the mosaic structure, and in the crystal lattice spaces, and its effect on hardness and elastic properties of metals.—J. C. R.

The Absorption of Nitrogen into Iron during Dry Machining. L. Moreau. (Métaux, Corrosion, Usure, 1944, vol. 19, Mar.–Apr., pp. 53–54). In order to examine the circumstances in which atmospheric nitrogen is absorbed into iron and steel, a series of tests was carried out to enable the chemical determination of nitrogen to be made (1) on large test-pieces obtained by cutting and then rolling, (2) on milling chips and (3) on fine milling powder. The results obtained are shown and briefly discussed. When test-pieces were obtained by dry machining as above, the temperature at the surface where the chips were removed was very high and sometimes even exceeded the melting point of the metal and resulted in nitriding. Consequently, from an analytical point of view, test-pieces should be cut by hand and not by high-speed steel tools.—J. C. R.

Some Practical Remarks on Gases in Steel and Cast Iron. E. Eyt. (Fonderie, 1946, Special Issue, pp. 438–439). A brief account is given of the occurrence of gases in metals and the defects which arise when an excess is present. The causes of blowhole and flakes in steels are also examined.—J. C. R.

The Influence of Manganese on the Polymorphic Transition in Alloys of Iron with Chromium. A. T. Grigor'ev and D. L. Kudryavtsev. (Bulletin de l'Académie des Sciences, U.R.S.S., Classe des Sciences Chimiques, 1947, pp. 329–335 [in Russian]: Chemical Abstracts,

1948, vol. 42, May 10, col. 2910). This was an investigation of the 0·6% and 1·4% manganese sections of the iron–chromium–manganese system up to 22% chromium. The alloys studied were made in a low-silica alumina crucible in a high-frequency furnace using electrolytic chromium, manganese, and Armco iron. The chromium content of the eight 0·6% manganese (actually 0·48–0·82% manganese) specimens covered the range 3·89% to 22·57%, and the chromium content of the seven 1·4% manganese (1·03–1·72%) specimens covered the range 6·65% to 22·07%. Dilatometric curves were obtained for annealed alloys with a Chevenard dilatometer and heating and cooling rates of 200°/hr. The $\alpha \rightleftharpoons \gamma$ transformation disappeared in the 0·6% manganese alloys at 14·56% chromium and in the 1·4% manganese alloys at 15·53% chromium. The minimum temperature of the $\gamma \rightarrow \alpha$ transformation (cooling) falls continuously with increase in chromium content, while the temperature hysteresis of this reaction increases to a value of 400° at 11·27% chromium and 1·4% manganese. The presence of a small amount of manganese changed the character of the transformation depending on the direction. The transformation on heating is that characteristic of a closed γ loop; the transformation on cooling is that characteristic of a diagram having an open γ region. The alloys obtained by the latter process were concluded to be in a non-equilibrium condition, from the results of specific electric resistance measurements on them. Rockwell hardness values were obtained on specimens homogenized at 1200° and quenched after annealing 15 days at temperatures between 800° and 1200°. The results showed that with increasing manganese content the boundaries of the γ loop widen while shifting to a region of lower temperature and higher concentration. An investigation of microstructures gave results that agreed exactly with those of the hardness data. The fact that quenching does not succeed in retaining the austenite structure was explained by the fact that, on cooling, the diagram is that having an open γ field. The fact that specific electric resistance data obtained on annealed specimens with a Thompson double bridge failed to correlate with the other results was explained on the basis of non-equilibrium structure of these specimens. Values are given for 25° and 100° and are of the order of 40×10^{-6}. Twenty references are given.

New Steels. J. G. Morrow. (Canadian Metals and Metallurgical Industries, 1948, vol. 11, Mar., pp. 14–15, 34). This is a brief discourse on the properties and applications of alloy steels.—M. A. V.

Influence of Nitrogen on the Hardenability and Notch Toughness of Boron-Treated Steels. T. G. Digges and F. M. Reinhart. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 1124–1146). End-quench and Charpy impact tests were made to determine the influence of nitrogen on the hardenability and notch-toughness of boron-treated steels. Similar tests were carried out with high-nitrogen steels containing about 0·0015% of boron and varying amounts of titanium, chromium, or zirconium.

Nitrogen had no significant effect on the hardenability of the steels without boron. Boron increased the hardenability of all the low-nitrogen steels, but its presence was relatively ineffective in the high-nitrogen steels that did not contain titanium or zirconium. Improvement in hardenability due to boron, however, was attained in high-nitrogen steels by including sufficient amounts of either titanium or zirconium. The notch-toughness of the fully hardened and tempered steels was not materially affected by nitrogen or boron whereas the notch toughness of the high-nitrogen/boron steels containing titanium, chromium, or zirconium varied with the concentration of these elements, hardness, and test temperature.

The Effect of Carbon Content on the Hardenability of Boron Steels. G. D. Rahrer and C. D. Armstrong. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 1099–1123). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 530.

The Effect of Copper on the Properties of High-Carbon Chromium Steel. I. P. Latuntsov. (Stal, 1948, No. 3, pp. 255–258). [In Russian]. Specimens of high-carbon chromium steels with from zero to 1% of copper were tested by dilatometric methods to determine their Ac_1 and Ar_1 points; their microstructure, and mechanical properties after tempering, and after quenching and drawing, were investigated. The following conclusions were drawn: Copper lowers the critical points of steel while increasing the temperature-hysteresis; the pearlite in tempered steel tends to assume the form of fine, evenly distributed grains; the tensile strength is increased and the specific elongation and contraction are decreased by copper for tempered steels; more than 0·25% of copper lowers the impact strength; it improves the structure of quenched steel, giving increased impact strength but somewhat diminished strength under static deformation, and high-carbon chromium steel is more easily tempered when copper is present.—S. K.

The Stainless Steels. L. F. Spencer. (Steel Processing, 1947, vol. 33, Aug., pp. 474–478, 508; Sept., pp. 558–563, 584; Oct., pp. 624–629; Dec., pp. 755–760; 1948, vol. 34, Jan., pp. 36–40, 51; Feb., pp. 75–79; Mar., pp. 127–133, 153, 156, 157; Apr., pp. 198–203, 218). A general account is given of the classification and uses of stainless steels. In the second part of the article the author discusses at length forging practice for stainless steel. The third part deals with the drawing properties and gives details of suitable lubricants for drawing. In the fourth part the hardening and annealing of low-, medium-, and high-carbon stainless steels are dealt with. The fifth part describes the welding of chromium and chromium–nickel stainless steels by the "Unionmelt," atomic hydrogen, oxy-acetylene, and electrical resistance processes. The structure of the weld metal and the heat-affected zone is illustrated by photomicrographs.—R. A. R.

Alloy Spring Steels. E. T. Bittner. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 263–280). The strength properties, notch sensitivity, hardenability, grain size, oxidation loss, decarburization, fatigue characteristics, and quality of hot-rolled chromium–nickel–molybdenum steel, chromium–vanadium steel, and silicon–manganese steel for making hot-formed springs were studied. The best properties were exhibited by the first-named quality and the poorest by the third quality.—R. A. R.

An Investigation of Tempered Chromium–Silicon Spring Steels. H. J. Elmendorf. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 281–301). *See* Journ. I. and S.I., 1948, vol. 158, Mar., p. 399.

Iron-Manganese Alloys. J. R. Long, T. R. Graham, and A. H. Roberson. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 401–419). The properties of cold-worked and normalized steel containing 26% to 48% of manganese were investigated. The alloys with 26–29% of manganese work-hardened very rapidly because of the formation of the ε-phase during cold rolling. The tensile strength of the 26·6% alloy rises from 95,100 to 214,000 lb/sq in with 60% reduction by cold rolling, and yield strength rises from 23,200 to 204,000 lb/sq in, whereas the elongation decreases from 45% to 1%. The 40% to 48% alloys

increase in strength with cold working but do not attain tensile strengths exceeding about 140,000 lb/sq in. The electrical resistivity of low managanese–iron alloys decreases sharply with cold working, but returns substantially to the value in the normalized state with heat-treatment at 315° C.—R. A. R.

Cast Heat Resistant Alloys of the 26% Chromium 20% Nickel Type. Part I. H. S. Avery and C. R. Wilks. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 529–584). The mechanical properties at room temperature and the creep properties at 760° to 1095° C. of cast HK 26/20 chromium–nickel steels, as well as the thermal expansion, resistance to carburization and to corrosion by hot gases are presented and discussed. The effect of the carbon content is marked. Increasing the carbon lowers the ductility at ordinary temperature but increases the hot strength and life expectancy without impairing the hot ductility. These properties are compared with those of 26/12 and 16/35 chromium–nickel steels, and the 26/20 steel is found to be the best all-purpose heat-resistant alloy.—R. A. R.

The Effect of Homogenization on Cast Steels. R. J. Marcotte and C. T. Eddy. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 649–676). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 532.

Investigations on Torsion Bar Suspension Springs. O. Föppl. (Engineers' Digest [London] 1948, vol. 9, Apr., pp. 117–120). This is an abridged translation of three papers in German which appeared in Metalloberfläche, 1947, vol. 1, pp. 133–137; Werkstatt und Betrieb, 1946, vol. 79, pp. 205–208 and Ingenieur-Archiv 1947, vol. 16, pp. 107–110.

The Influence of Forged Steel Parts and Welded Assemblies on the Future Prospects of Cast Steels. A. Hencks. (Revue Technique Luxembourgeoise, 1948, vol. 40, Apr.–June, pp. 71–79). This is a summary of a paper read at the Centenary Congress of the Association des Ingénieurs Sortis de l'Ecole de Liége, held at Liége on September 10, 1947. The structure and mechanical properties of cast, wrought, and welded steel parts are compared. Methods of preventing defects in cast steel parts and the effects of heat-treatment on their mechanical properties are discussed. Possible uses of cast hypereutectoid steels are briefly mentioned as well as some new processes of casting steel. Future prospects for cast steels are discussed.—R. F. F.

Physical Characteristics of Steel for Tubular Products. A. B. Wilder. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 596–614). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 539.

Improvements in Acid Resisting Silicon Iron Alloys. J. E. Hurst. (Transactions of the Institution of Chemical Engineers, 1944, vol. 22, pp. 72–80). *See* Journ. I. and S.I., 1944, No. II, p. 114A.

Contribution to the Study of High-Mechanical Resistance Special Cast Irons. G. Delbart and R. Potaszkin. (Fonderie, 1946, Special Issue, pp. 444–445). A summary is presented of an investigation into the mechanical properties of nine nickel–molybdenum, one nickel–chromium and two unalloyed cast irons, manufactured in a basic electric furnace.—J. C. R.

Recent Developments Concerning the Properties of Cast Steels. C. W. Briggs. (Transactions of the American Society of Mechanical Engineers, 1948, vol. 70, Jan., pp. 37–47). *See* Journ. I. and S.I., 1948, vol. 158, Feb., p. 282.—R. A. R.

The Rôle of Meehanite Metal Castings in Engineering Production. C. R. Austin. (Transactions of the American Society of Mechanical Engineers, 1948, vol. 70, Feb., pp. 99–109). The application of high-strength cast iron for constructional purposes is discussed and data on the properties (including expansion and creep) of some of these irons are presented. Several examples of large and small castings in Meehanite are described and illustrated.—R. A. R.

Corrosion and the Chemist. The Metallurgy Section, Dominion Laboratory, D.S.I.R. (New Zealand Engineering, 1948, vol. 3, Feb. 10, pp. 148–149). The metallurgical research activities of the Dominion Laboratory in Wellington are briefly described. These include spectrographic and electrolytic analysis. Physical metallurgy, corrosion tests, and tests on automatic arc-welding machines.—M. A. V.

METALLOGRAPHY

Influence of a Small Quantity of Hydrogen on the Modulus of Elasticity of Iron and Evidence of a Sub-Structure of Iron. G. Chaudron and L. Moreau. (Métaux, Corrosion, Usure, 1944, vol. 19, Mar.–Apr., pp. 51–52). The authors have investigated the effect on the modulus of elasticity of iron of a low hydrogen content (10 c.c./g of metal) absorbed by electrolysis using a 5-V. supply. In further experiments a monocrystal of iron was charged to 120 V at – 10° C. and absorbed 150 c.c. of hydrogen per 100 g of iron. After mechanical polishing and ordinary etching, examination at 2000 magnifications revealed a lined sub-structure.—J. C. R.

Electron Microscopy and Its Industrial Applications. P. Coheur. (Revue Universelle des Mines, 1948, Series 9, vol. 4, May, pp. 313–327). The electron microscope is described and examples of industrial applications are given with special reference to the morphology of powders and metallography.—R. F. F.

A Soviet Electron Microscope. V. N. Vertsner. (Zavodskaya Laboratoriya, 1947, vol. 13, Nov., pp. 1364–1375). [In Russian].

Methods of Investigations Using the Electron Microscope. A. I. Frimer and S. L. Pupko. (Zavodskaya Laboratoriya, 1947, vol. 13, Nov., pp. 1375–1387). [In Russian].

The Calculation of Microscope Objectives. C. Moser. (Schweizer Archiv, 1948, vol. 14, Mar., pp. 70–72).

Transparent Mounting Material for Metallurgical Specimens. R. Kiessling. (Jernkontorets Annaler, 1948, vol. 132, No. 4, pp. 110–111). [In Swedish]. A method of preparing and using methyl methacrylate as a mounting material for small metallurgical specimens is described.—R. A. R.

Magnetic Methods for Microscopic Examination. S. Bergh. (Jernkontorets Annaler, 1948, vol. 132, No. 4, pp. 105–109). [In Swedish]. In order to make ferromagnetic constituents in austenitic steels visible in the microscope Akimov immersed the specimen in a suspension of a magnetic powder in alcohol. Some difficulties with this method are pointed out and the author proposes a suspension of Fe_3O_4 in Clericis solution (2 parts of thallium formate with 1 part of thallium malonate, sp. gr. 4·20 at 15° C.). A thin film of this under a cover glass is applied to the specimen to which a bar magnet is fixed with plasticine. Higher magnification can be used and there is no difficulty due to successive sedimentation of magnetic powder.—R. A. R.

History of Crystal Growth Revealed by Fractography. C. A. Zapffe, F. K. Landgraf, jun., and C. O. Worden, jun. (Science, 1948, vol. 107, Mar. 26, pp. 320–321). The technique of "fractography" *i.e.*, the microscopic study of fracture facets at high magnification, has been applied to the study of crystal growth in metals and alloys. The examples described include chromium ferrite and ζ-silicon ferrite; both exhibit intrinsic weakness. The patterns obtained with different metals and alloys are sufficiently characteristic to serve as a means of identification.—M. A. V.

A Modern Picture of Metal Structure. E. Schwarz-Bergkampf. (Berg- und Hüttenmännische Monatshefte der Montanistischen Hochschule in Leoben, 1948, vol. 93, Jan.–Mar., pp. 23–28). Modern theories of the molecular and atomic structure of metals are outlined.—M. A. V.

Electrochemical Theory of the Action of Reagents Used in the Microscopic Metallographic Examination of Grey Cast Irons. Application to Steelworks Ingot Mould Irons. L. F. Girardet. (Fonderie, 1946, Special Issue, pp. 455–461). After outlining the mechanism of the electrochemical action of reagents on cast irons, the author describes its application in the microscopical study of ingot mould irons.—J. C. R.

Recrystallization as a Measurement of Relative Shot Peening Intensities. K. B. Valentine. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 420–434). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 540.

Detection of As-Cast Austenite Grain Size in Heat Treated Cast Alloy Steels. E. A. Loria. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 677–702). *See* Journ. I. and S.I., 1948, vol. 158, Mar., p. 412.

Some Characteristics of the Metastable Austenite of 4 to 6% Chromium + 1½% Molybdenum Cast Steel. G. J. Guarnieri and J. J. Kanter. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 1147–1164). A technique is described for conducting both high-temperature tensile and impact tests on metastable austenite in 5% chromium 0·5% molybdenum cast steel as well as for indicating the magnitude and nature of the effect of stress on the austenite reaction. Stresses capable of plastically deforming the austenite at the transformation temperature definitely accelerated both the nucleation and the growth process of the reaction at least at temperatures below the apex of the time-temperature-transformation curve. This stress effect may be a factor causing more rapid transformation when normalizing castings of heavy section of air-hardening steels not reflected by the slower reaction taking place in small specimens cooled at corresponding rates.—R. A. R.

Macrosegregation in Some Alloy Steel Ingots. J. W. Spretnak. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 897–921). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 540.

The Distribution of Oxygen and Nitrogen in an Alloy Steel Ingot. C. F. Sawyer, J. W. Spretnak and G. Derge. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 922–934). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 540.

The Location of Alloying Metals in White Cast Iron. H. A. Schwartz and J. Hedberg. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 223–262). An attempt is made to determine how alloying elements in white cast iron are distributed between cementite and ferrite during freezing and cooling. The two phases were separated by electrolytic methods. Molybdenum and chromium follow the Nernst partition principle. For molybdenum the partition coefficient (amount in cementite divided by amount in ferrite) is practically infinite; for chromium it is about 5; for nickel it is about 5, but the initial nickel additions are all in or with the cementite up to a concentration, in that phase, of about 0·3%; for manganese (as metal and assuming that all the sulphur is present as MnS) the coefficient varies with the Mn/S ratio, being zero if the ratio is above 0·24, and it increases as this ratio decreases.—R. A. R.

Malleable Cast Iron. H. G. Hall. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. B46–B59). *See* Journ. I. and S.I., 1947, vol. 156, Aug., p. 575.

Stability of Steels as Affected by Temperature. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 207–210). The susceptibility to graphitization of welded chromium–molybdenum steel (C 0·19%, Mn 0·60%, Cr 0·46%, Mo 0·46%) after long-time ageing at 1100° F. was studied. Spheroidization of carbides in the heat-affected zone, but not to any great extent, was observed. A fine precipitate was noted in the ferritic areas of most of the specimens, apparently in greater amounts in the previously annealed specimens.—R. A. R.

Graphite Formation in Grey Cast Iron. H. Morrogh and W. J. Williams. (Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. A47–A63). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 313.

X-Ray Study of the Splitting of a Single Crystal of Iron by Hydrogen Absorption. J. Bénard, G. Chaudron, and J. Talbot. (Métaux, Corrosion, Usure, 1944, vol. 19, Nov.–Dec., p. 106). After hours of electrolytic charging with hydrogen, single crystals of iron are reduced to a large number of small crystals. This has been demonstrated by Laue and Debye-Scherrer diagrams. As the electrolytic charging with hydrogen continued, the Laue diagram progressively disappeared and the Debye-Scherrer diagram became more pronounced thereby indicating the splitting of the large or single crystals.—J. C. R.

Eutectic Crystallization. E. Scheil. (Metallforschung, 1946, vol. 1, July–Aug., pp. 1–11). A distinction is drawn between "normal" and "anomalous" structures obtained by crystallization of the eutectic from alloy systems. "Normal" crystallization is characterized by well-defined crystallization fronts and a regular arrangement of lamellæ in the grains; but "anomalous" crystallization is irregular. The work of various investigators on the mechanism of both types of crystallization is reviewed, with numerous examples, mainly of non-ferrous alloy systems.—M. A. V.

The Calculation of the Eutectic Crystallization Velocity, with Pearlite As an Example. E. Scheil. (Metallforschung, 1946, vol. 1, Oct.–Nov., pp. 123–130). The crystallization of ferrite is associated with that of the cementite in lamellar pearlite, but pearlite is formed by two other processes, the formation of new lamellæ and their growth. This formation of new lamellæ is assisted much more by primary cementite than by primary ferrite. To calculate the crystallization velocity of pearlite the crystallization is idealized to a stationary process and the calculation is made for the case of a plane crystallization front. As the saturation curves of undercooled austenite for ferrite and cementite are used in the calculation, these are calculated assuming that the heat of solution in the austenite can be neglected and that not all the spaces in the austenite lattice are occupied, except occasionally the centres of the octahedra. Assuming that the austenite above the cementite lamellæ is almost saturated with carbon, the calculation gives the relation between the temperature and the product of the crystallization velocity and the distance between adjacent lamellæ. This product is found to be much less than that obtained by measurements. The explanation appears to be that the diffusion velocity at the crystallization front is much higher than that within an undisturbed crystal. A second theory for the formation of pearlite based on a temporary separation from homogeneous austenite is discussed and rejected.—R. A. R.

The Slip of Metal Crystals. U. Dehlinger. (Metallforschung, 1946, vol. 1, July–Aug., pp. 11–17). Atomic relationships in the plastic deformation of single crystals by slip are discussed. It is shown that it is possible to apply quantitatively the slip of single crystals to that

of polycrystalline materials. Slip in single crystals is due to the combined effects of (*a*) temperature, (*b*) notch effect of the mosaic boundaries, and (*c*) movement of the displacement through the mosaic domains. The increase in strength with slip is due to " suspended " displacement. It is shown that when slip begins, *i.e.*, at well below the elastic limit, elastic stresses build up near the grain boundaries ; these stresses increase with increasing deformation in the case of hexagonal-lattice metals, but with cubic-lattice metals they remain constant after reaching the elastic limit because of secondary slip.—R. A. R.

A Study of the Metallurgical Characteristics of Three Induction-Hardened Steels Heated at Various Rates. J. W. Poynter. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 1077–1098). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 538.

Comparison of Crystal Structures of Ten Wrought Heat-Resisting Alloys at Elevated Temperatures with Their Crystal Structures at Room Temperatures. J. H. Kittell. (National Advisory Committee for Aeronautics, 1947, Technical Note No. 1488 : Chemical Abstracts, 1948, vol. 42, Apr. 10, col. 2218). Specimens of gas-turbine alloys were held at 1200°, 1500°, and 1800° F. for 1 hr and observations were made of the crystal structure at these temperatures using a modified Geiger counter X-ray spectrometer. In addition, dilatation curves were obtained on heating specimens at 20° F./min up to 1000° F., and at 5° F./min above 1000° F. The alloys investigated were : S-816, S-590, Hastelloy-B, 19-9 W-Mo, N-155, 16-25-6, K-42-B, Inconel X, Nimonic 80, and type 347 stainless. The 19-9 W-Mo alloy when heated began to transform from a two-phase mixture of body-centred and face-centred cubic crystal structure to a single phase of face-centred cubic crystal structure between 1400–1450° F. The transformation was completed between 1450–1500° F. The other nine alloys retained their room-temperature crystal structure at each temperature studied. Thermal-dilatation curves of the alloys showed no discontinuities in thermal expansion at temperature up to 2150° F.

The Crystal Structures of Ferrites and Analogous Metal-Oxides. E. J. W. Verwey, P. W. Haayman, and E. L. Heilmann. (Philips Technical Review, 1947, vol. 9, pp. 185–190 : Chemical Abstracts, 1948, vol. 42, Apr. 10, col. 2153). The importance of ferrites in the general formula MFe_2O_4 (M is a bivalent metal) in electrotechnology is pointed out. The particularly important ferrites are those with a crystal structure analogous to the structure of the mineral spinel. The dependence of the magnetic and electrical properties of these ferrites, and the mixed crystals of which they form a part, are attributed to their crystal structure. Some of the theoretical results are compared with X-ray diffraction data.

The Influence of Titanium and of Combined Additions of Boron, Vanadium, and Titanium on the Crystallization of Steel. V. E. Neimark, I. B. Piletskaia and R. I. Entin. (Stal, 1948, No. 3, pp. 248–254). [In Russian]. Two series of steels with 0·45–0·55% and 0·8–1% of carbon respectively, were used for the investigation of the effects of titanium and of combined additions of titanium, vanadium, and boron on the structure of cast steel. The steels were made by melting bar iron and pig iron in a 30-kg high-frequency furnace, deoxidizing with ferromanganese and ferrosilicon and killing with aluminium. Series of ingots of each steel, with increasing titanium were made by tapping the steel for the first ingot and adding ferrotitanium to the metal in the furnace before the next tapping. Specimens suitable for the investigation of the isothermal decomposition of austenite and for the determination of macro- and microstructure and of hardness were prepared from each ingot.

Additions of less than about 0·1% of titanium were found to have only a slight effect on the fracture, but a greater addition gave a much closer-grained macrostructure. Approximately 0·03–0·1% of titanium in the steel resulted in considerable change in its primary crystallization structure with diminished austenite grain-size, and absence of transcrystallization. The same effects, but smaller in extent, were produced by larger additions of titanium. The stability of austenite at various temperatures was increased to a considerable extent by 0·02–0·1% of titanium, but more than this sharply decreased this stability. The greatest tempering susceptibility was found when 0·09–0·1% was present. Combined additions of boron 0·003%, vanadium 0·05–0·06%, and titanium 0·03–0·04% to carbon steel gave an improved primary crystallization structure in the ingot and a considerably increased austenite stability and tempering susceptibility. The increase in tempering susceptibility resulting from such a combined addition was found to be approximately double that produced by the addition of 0·003% of boron. These changes in structure were reflected in changes of hardness.—S. K.

The Dimensional Stability of Steel. Part II.—Further Experiments on Sub-Atmospheric Transformations. S. G. Fletcher, B. L. Averbach, and H. Cohen. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 703–727). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 537.

The Dimensional Stability of Steel. Part III—Decomposition of Martensite and Austenite at Room Temperature. B. L. Averbach, M. Cohen, and S. G. Fletcher. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 728–757). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 539.

Acicular Transformations in Alloy Steel. E. A. Loria and H. D. Shepard. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 758–774). *See* Journ. I. and S.I., 1948, vol. 158, Apr., p. 539.

Metallography of Hot-Dipped Galvanized Coatings. D. H. Rowland. (Transactions of the American Society for Metals, 1948, vol. 40, pp. 983–1011). *See* Journ. I. and S.I., 1948, vol. 158, Mar., p. 405.

Notes on Some Equilibrium Diagrams. L. Grenet. (Echo des Mines, 1948, Apr., pp. 70–71). Some peculiarities of the iron-nickel, carbon-oxygen, and iron-carbon-oxygen diagrams are discussed.—R. F. F.

CORROSION

Corrosion—Causes and Prevention. F. J. Maffei. (Boletim da Associação de Metais, 1947, vol. 3, pp. 419–441 : Instituto de Pesquisas Tecnológicas, Separata No. 178 : Chemical Abstracts, 1948, vol. 42, May 10, col. 2912). A review is presented of the electro-chemistry of corrosion, including passivity, metallic coatings, cathodic protection, and the effect of impurities and alloying metals.

The Fight against Rust—The Cancer of Metals. (Dansk Teknisk Tidsskrift, 1948, vol. 72, Jan., pp. 1–4). [In Danish].

Mechanism of Oxidation and Tarnishing. U. R. Evans. (Corrosion, 1948, vol. 4, Apr., pp. 149–171). The mean thickness of oxide on a surface may be related to the time of exposure in one of three ways, linearly, parabolically, or logarithmically. It is found that, in practice, oxidation may appear to take place by any of these relations and often changes from one relation to another. The author, as a result of the study of tarnishing on a number of metals, concludes that the growth of a layer normally takes place because of the migration of cations and electrons from the base metal and that growth

therefore follows a parabolic relation with time. If, however, the film breaks down as a result of its own growth, changes will occur. Blistering, caused by high cohesion in conjunction with poor adhesion, will lead to rectilinear thickening if oxygen enters the blister, but to logarithmic thickening if it does not, as cavity barriers parallel to the surface now impede cation migration. Flaking off of the tarnish film leads to resumption of oxidation at the original rate, while shear cracking, occurring where the adhesion of the film is high and its cohesion low, should lead to parabolic or rectilinear thickening or intermediate forms. This theory explains the known experimental results and accounts for the fact that conditions prevailing at the outset of exposure dictate subsequent behaviour.—J. P. S.

Corrosion Inhibitors in Theory and Practice. R. D. Misch and H. J. McDonald. (Wire and Wire Products, 1948, vol. 23, Mar., pp. 221–226, 260–264). The mechanism of the action of inhibitors is discussed on the basis of present knowledge. Inhibitors are divided into three classes, namely, surface-conversion, adsorption, and diffusion inhibitors, and examples of each are considered. An adsorption-concentration curve for inhibitors is presented; it shows that at high concentrations a constant amount (enough for a mono-atomic layer) is adsorbed. There is a critical concentration which will just maintain such a layer and a concentration at slightly above the critical amount is the most economical. There are 36 references to the literature.—R. A. R.

Rate of Breakdown and Mechanism of Nitrate Inhibition of Steel Corrosion. R. Pyke and M. Cohen. (Journal of the Electrochemical Society, 1948, vol. 93, Mar., pp. 63–78). A study was made of the effect of temperature and concentration on the breakdown of sodium nitrate in solution in the presence of steel. The end breakdown product of nitrite was identified as ammonia and the effect of the ratio of cathodic and anodic areas on the consumption of nitrite was determined. The rate of consumption of nitrite was found to be dependent on the rate of steel corrosion. A mechanism of reduction of nitrite by adsorption at anodic areas followed by reduction of cathodic hydrogen to give an adherent protective oxide is proposed.—J. P. S.

The Relationship between Stress Corrosion and Stress and Temperature. G. Wassermann. (Zeitschrift für Metallkunde, 1948, vol. 39, Mar., pp. 66–71). The literature shows that when results of stress-corrosion tests on carbon steel are given by plotting stress against life (in hours) on a log-log scale a straight line is obtained. The author has evaluated stress-corrosion test data on austenitic steels and non-ferrous alloys from the literature in a similar manner, and found the straight-line relationship was obtained in each case. Great care must be exercised in attempting to reduce the testing time in these tests by raising the temperature.—R. A. R.

Conditions for Passivation of Stainless Steels and Its Practical Application. L. Guitton. (Metal Treatment, 1948, vol. 15, Spring Issue, pp. 3–13). The passivation of stainless steels by chemical and anodic treatments is discussed. Experiments are described which show that preliminary sensitization considerably facilitated and accelerated spontaneous passivation in aerated acid; The best sensitizing solution for 18/8 stainless steel is a mixture of 10% by volume nitric acid (sp. gr. 1·33) and 2% by weight sodium fluoride, employed at below 60° C. In investigating the resistance to sulphuric acid, anodic treatment was particularly effective when the electrolytes used were of similar composition to those against which resistance was required.

Passivity affects only the outermost layers of atoms on the surface of metal, whereas sensitization affects a depth of the order of 0·1 mm.

The mechanisms of sensitization and chemical passivation are explained. Sensitization is destroyed at a relatively high temperature which varies with the composition of the steel. The passivity of a mechanically prepared surface is destroyed *in vacuo* at room temperature. It is concluded that passivation of 18/8 steel corresponds to the adsorption of oxygen on the surface of the metal. After sensitization the adsorption is chemical in nature and stoichiometric, the oxygen being bound firmly to the metal, atom to atom. Activation brought about by acid attack is not merely an increase in the apparent surface, but is mainly a mass modification with permanent lattice distortion.

The sensitization and passivation techniques described are successful not only with plain specimens, but also with welded and cold-deformed specimens, and on actual assemblies.—R. A. R.

Electrometric Study of the Behaviour of Rustless Steels in Acids. L. Guitton. (Revue de Métallurgie, Mémoires, 1947, vol. 44, Nov.–Dec., pp. 330–348). After giving details of the electrometric method and apparatus used in the work, the author presents an account of his study of the corrosion of an 18% chromium, 10% manganese rustless steel in a 5% oxalic acid solution. The potential-time curves for periods of up to 1000 hr showed that the principal factor in the scatter of results often observed, was the degree of aeration of the solutions at a certain critical phase of the immersion and more precisely, with the material used, the access of atmospheric air to the vessels containing the solution. There were three horizontals in the potential curves: (1) The first horizontal, electronegative, with visible corrosion; (2) the second, less electronegative, a transitional horizontal, unstable in character, corresponding to slower corrosion, dissolved oxygen taking effect; and (3) the third horizontal, electropositive, stable.

Specimens remained about 10 min at the first horizontal and some hours at the second; according to whether air had access to the solution or not; they then passed to the third horizontal or fell back to the first; in the first case there was definite passivation, in the second definite corrosion. When the solution was agitated the transition horizontal was suppressed and final passivation was achieved. Prior attack with hydrochloric acid caused the sand-blasted specimens to become passive very quickly, the second horizontal, and even the first in some cases, disappearing from the potential-time curves. This so-called "sensitization" differs from passivation, because the initial potential has the same electronegative value as that of a specimen sand-blasted only, and the same initial rate of solution, but its mechanism is not understood.—A. E. C.

Fretting Corrosion—How to Eliminate it. E. V. Albert. (Steel, 1948, vol. 122, Apr. 5, pp. 72–76, 96, 98). Fretting corrosion is a mechanical-chemical effect often encountered in bearing surfaces having little relative motion but subject to vibration, for example ball and needle bearings in automobiles transported by rail, aircraft control bearings, and railway rail-end joints. In every case there occurs oxidation of the contact areas which are at the same time both loaded and subjected to vibration. The theories of occurrence include: (1) That which ascribes it to the successive wearing away of oxide films, (2) that which puts it down to direct oxidation due to localized heating from the severance of the cohesion bonds between the surfaces. Methods of eliminating it include the elimination of air by the use of high-viscosity, or low-viscosity and high-film-strength, lubricants, the reduction of friction

by lubricants, and by chromium plating, the increase of friction by surface treatment, which prevents slipping, the use of gaskets to absorb motion, and the hardening of the surfaces by changes in the composition of the materials or by the introduction of residual stresses by shot-peening or surface-rolling.—J. P. S.

Testing and Selection of Inhibitors for Corrosive High Pressure Condensate Wells. D. A. Shock. (Corrosion, 1948, vol. 4, Apr., pp. 179–185). The nature and properties of inhibitors are described with special reference to conditions in condensate wells in oilfields where corrosive waters and hydrocarbons occur.—J. P. S.

Boiler Feed Pump Corrosion ? Here's What You Can Do about It. H. L. Ross. (Power Generation, 1948, vol. 52, No. 2, pp. 104, 106, 108 : Chemical Abstracts, 1948, vol. 42, Apr. 10, col. 2372). Lower *p*H values and lower total solids resulting from refinements in feed-water treatment have created unexpected problems as to corrosion and erosion. Raising the *p*H and recirculating boiler water to raise the total solids are suggested. The possibilities of successful protective coatings and the use of new materials in new pumps are also touched upon.

Station Design and Material Composition as Factors in Boiler Corrosion. R. B. Donworth. (American Society for Testing Materials, 1948, Preprint No. 106). This paper shows the physical relationship of the metals and materials used in modern electric power stations and the influence of design on the corrosion and erosion of steam turbine installations.—R. A. R.

Intergranular Cracking of Boiler Plates. (British Engine, Boiler and Electrical Insurance Co., Ltd., Technical Report for 1938, 1948, pp. 7–10). Examination of the circular seams of a boiler showed that difficulty had been experienced in keeping these tight and that attempts had therefore been made to weld up the seam. Intergranular corrosion was clearly visible in the plate and in some of the rivet heads, but it is concluded that in this case the embrittlement was not due to chemical action but it was assisted by it. It is also inferred that transgranular cracks may be formed in solid-forged or welded boiler-drums which afterwards extend in an intergranular fashion.—J. P. S.

An Investigation of Boiler-Drum Steel after 40 Years of Service. H. S. Blumberg and S. V. Smith. (Transactions of the American Society of Mechanical Engineers, 1948, vol. 70, Apr., pp. 185–200). An investigation has been made of the steel of a number of boiler drums installed in 1901 and 1902 ; the analysis was found to be C 0·235%, Mn 0·355%, P 0·011%, and S 0·036% on the average. Tensile strengths exceeded the A.S.T.M. A-70 boiler code requirements, and no signs of general corrosion or caustic embrittlement were detected. It was noted that periodic inspection and maintenance had been extremely thorough and that the excellent condition was probably due to this.—J. P. S.

The Statistics of Boiler Embrittlement. C. D. Weir. (Transactions of the American Society of Mechanical Engineers, 1948, vol. 70, Apr., pp. 253–255). A statistical study of tests carried out with the Schroeder detector, to investigate the susceptibility to embrittlement of boiler plate by certain feed waters is described. The detector is constructed so that the feed water, under boiler pressure, leaks past the tensile-stressed side of a specimen of the steel.

Mathematical analysis of results published by Partridge, Kaufman, and Hall (Transactions of the American Society of Mechanical Engineers, 1942, vol. 64, pp. 417–425) indicates that : (1) Variations of composition of feed water in hydroxide, chloride, silica, oxide, and phosphate do not materially influence susceptibility to cracking ; (2) that sulphate does stimulate cracking when present to the extent of 200–600 parts per million, though outside this range it offers a slight protection ; (3) there is no evidence that a high Na_2SO_4/NaOH ratio is beneficial, or that the association of a high value of this ratio with a high NaCl/NaOH ratio reduces the incidence of cracking, and (4) the presence of appreciable amounts of tannin in boiler water gives remarkable immunity from attack.—J. P. S.

Factors of Importance in the Atmospheric Corrosion Testing of Low-Alloy Steels. H. R. Copson. (American Society for Testing Materials, 1948, Preprint No. 20). Factors influencing atmospheric corrosion tests are considered on the basis of results obtained with panels of a large number of low-alloy steels, with notes on the different methods of evaluating the results. Over one year the weight loss for a straight nickel steel was less than for a steel with part of the nickel replaced by chromium or copper, but over five years the weight loss for the latter was less. Small additions of manganese to copper-bearing steels were beneficial in resisting marine atmospheres and the benefit increases with time. Pit-depth and weight-loss measurements give different results. Chromium steels generally suffer from deeper pits than nickel steels.—R. A. R.

Laboratory Corrosion Tests of Iron and Steel Pipes. G. A. Ellinger, L. J. Waldron, and S. B. Marzolf. (American Society for Testing Materials, 1948, Preprint No. 21). Laboratory corrosion tests were carried out by circulating tap water through uncoated pipes and measuring the weight loss and depths of pitting over a period of 10 years. Three pipes were of open-hearth steel, two of ingot iron, three of wrought iron, one of centrifugally cast iron, and one of sand-cast iron. There was no great difference in the rates of corrosion of the wrought materials as measured by the two methods. Copper–molybdenum ingot iron and nickel-bearing wrought iron had the lowest corrosion rates.—R. A. R.

Atmospheric Durability of Steels Containing Nickel and Copper—Additional Exposure Data. N. B. Pilling and W. A. Wesley. (American Society for Testing Materials, 1948, Preprint No. 23). This report supplements information in an earlier paper on the corrosion resistance of panels of nickel–copper steels in different atmospheres (*see* Journ. I. and S.I., 1940, No. II., p. 163A). Additions of copper to a nickel steel increase the life, but the optimum addition is less than the nickel present, and remains well below 2% even with 4% of nickel. There is evidence that not only phosphorus but also silicon additions to nickel–copper steels increase the life in industrial atmospheres, whilst changes in the manganese and carbon have little effect.—R. A. R.

Rating Exposure Test Panels of Decorative Electrodeposited Cathodic Coatings. W. A. Wesley. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 803–821). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 316.

Inspection of Exposure Test Panels with Nondecorative, Electrodeposited Cathodic Coatings. H. A. Pray. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 822–825). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 316.

Inspection of Exposure Test Panels with Anodic Electrodeposited Coatings. G. Soderberg. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 826–831). *See* Journ. I. and S.I., 1947, vol. 157, Oct., p. 316.

Polarographic Study of Corrosion Phenomena. P. Van Rysselberghe, J. M. McGee, A. H. Gropp, R. D. Williams, and P. Delahay. (Corrosion and Material Protection, 1948, vol. 5, Mar.–Apr., pp. 11–16). This

paper describes the polarographic apparatus and methods used for the determination of oxygen, CO_2, H_2O_2, and hydrogen ions in solution, as a preliminary study before examining the rôles of these bodies in corrosion phenomena. Observations made in the application of these methods to the corrosion of certain metals and alloys will be presented later.—J. P. S.

Zinc as an Anticorrosive. A. H. Stuart. (Paint Manufacture, 1947, vol. 17, p. 383 : British Abstracts, B.I., 1948, Mar., col. 119–120). To determine the effect of zinc as an anticorrosive agent when not in direct electrical contact with mild steel, simple tests were carried out which indicated that the rate of corrosion was decreased as against unprotected steel. Thus a steel rod corroded less rapidly in water in the presence of zinc metal than in its absence, even though no electrical contact was established. It is suggested that the zinc exerts its well-known reducing properties by deoxidizing the water, or that zinc ions saturate the water and discourage the formation of iron ions. Nevertheless, it is recommended that direct contact of zinc dust with the zinc substrate should be achieved if possible, and that vehicles of the plasticized polystyrene type be used since a greater volume of zinc dust can be incorporated than in the usual media. A 4 : 1 ratio of zinc dust to zinc oxide reduces the tendency of zinc dust to settle.

Report of Subcommittee II on Performance Tests. (Proceedings of the American Society for Testing Materials 1947, vol. 47, pp. 195–199). The results of atmospheric corrosion tests on lead-coated steel panels are reported. Electroplated lead coatings gave better protection to steel in the industrial atmosphere of New York than in the coastal atmosphere of Kure Beach. R. A. R.

Report of Wire Inspection Committee on Field Tests of Wire and Wire Products. (Proceedings of the American Society for Testing Materials, 1947, vol. 47, pp. 120–137). This report presents comprehensive tables of the results of atmospheric exposure tests on wire and wire products after exposure for ten years in different atmospheres.—R. A. R.

ANALYSIS

Nuclear Physical Methods for Determining Small Amounts of Carbon. M. von Ardenne and F. Bernhard. (Zeitschrift für Physik, 1944, vol. 122, pp. 740–748 : Chemical Abstracts, 1948, vol. 42, May 10, col. 2866). The sample to be analysed is bombarded by a beam of 1 m.e.v. protons or deutrons ; these convert carbon atoms to radioactive $_7N^{13}$, whose measured activity is a function of the carbon content of the sample. The intermittent bombardment of a sample of known carbon content (usually silicon carbide) is used to calibrate the method. Surface impurities on the sample must be removed. The limit of detectibility is about 0·05%.

The Use of Aluminium and Magnesium Electrodes for the [Spectrographic] Determination of Nickel in Steels. O. N. Dubrovskaya. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 228–231 : Chemical Abstracts, 1948, vol. 42, May 10, col. 2888). The intensity ratio nickel-2992·6/iron-2990·4 is plotted as a function of pre-arcing time for flat and pointed aluminium and magnesium auxiliary electrodes. This ratio reached a plateau after the following pre-arcing times for the auxiliary electrode indicated : pointed aluminium 40 sec., flat aluminium 60 sec., pointed magnesium 10 sec., flat magnesium 15 sec. A Sventitsky alternating current arc was used at 5 amp ; the analytical gap was 2·5 mm.

New Spectrographs for Spectrochemical Analysis. (Design, Properties and Application to Investigations on Steel). F. Gössler. (Optik, 1946, vol. 1, Aug., pp. 85–133 : [Abstract]. Bulletin of the British Scientific Instrument Research Association, 1948, vol. 3, May, pp. 130–131). Design and performance data of various types of quartz spectrograph are given in the first part of this paper, after general introductory treatment on spectrographs. Among the types mentioned are : The ultraviolet spectrographs "Q 12" and "Q 24" and the automatic Littrow spectrograph "QG 55." The second part of the paper is taken up by detailed analysis results of a number of elements which are found in steel : Aluminium, cobalt, chromium, copper, manganese, molybdenum, nickel, niobium, silicon, tantalum, titanium, vanadium, and tungsten. A great number of photographs of spectra and wavelength tables are given in each case, comparing the performance of the three types of spectrograph.

On the Spectrochemical Determination of Vanadium in Iron Ores and Slags. A. Kvalheim. (Norsk Geologisk Tidsskrift, 1941, vol. 21, pp. 245–267). [In English]. The aim was to estimate from 0·2% to 2·0% of vanadium in concentrates or crude ores containing 20–70% of iron, and this was first tried using arc spectra of powders on carbon electrodes, and estimating the V/Fe ratio from arc lines of the two elements. The intensity ratio of the two lines was expressed in terms of the logarithm of the ratio of exposure times required to give equal blackenings in the two lines at an arbitrary density-level. The calibration graphs obtained when these log ratios were plotted against logarithms of concentrations of vanadium expressed as the percentage of iron present were linear for groups of similar minerals, but showed large variations according to the mineral, the presence of calcium causing a particularly large error. This led to an investigation of various line pairs, but for all cases some variation is produced by $CaCO_3$, while smaller changes are due to Al_2O_3 or MgO, and none to SiO_2. By using dilutions of the minerals with NaCl, the effect was found to be due to the evaporation of vanadium before iron in the arc to an extent which varies with the concentration of more easily ionized elements present, combined with an actual decrease of the intensity of the iron spectrum with increasing salt content while the vanadium lines remain relatively constant. This effect is plotted for $CaCO_3$ additions. By the use of chromium, added as Cr_2O_3 to the minerals, it was found that the relative intensity of vanadium and chromium lines is free from these disturbances, and can be used for the estimation of vanadium in ores and in slags ; if chromium is already present a mixture of the sample with one tenth its weight of Cr_2O_3 is arced as well as the sample, and then both the chromium and vanadium percentages can be calculated by a method described.—E. VAN S.

Detecting Residual Elements in Steel by Spectrographic Analysis. H. Swett. (Steel, 1948, vol. 122, May 3, pp. 106, 109, 128, 130). A Littrow high-dispersion spectrograph is used by the Bethlehem Steel Corporation, San Francisco, to determine residual nickel, chromium, molybdenum, copper, and tin introduced into the open-hearth bath when working on armament and war-surplus scrap. Several time-saving features have been introduced, such as automatic, pneumatic shifting from one spectrum region to another, automatic focusing in each region, solenoid operation of shutter, and automatic timing of operations. Either a high-voltage interrupted spark or a high-voltage alternating spark may be generated ; the line-intensity is measured by microphotometer, and the logarithmic ratio of the intensities of the line in question and an iron reference-line, referred to a table, enable the quantitative determination of the element present to be made.—J. P. S.

The Spectrographic Determination of Copper Contained in Low Concentrations in Iron and Steel. R. Castro and J. M. Phéline. (Spectrochimica Acta, 1947, vol. 3, pp. 18–39 : Chemical Abstracts, 1948, vol. 42, Apr. 20, col. 2541). Details and directions are given for the spectrographic determination of small amounts of copper in steel in the form of massive pieces or sheets. The spectra are excited in a controlled spark, or in an interrupted arc and are photographed with a Zeiss Qu 24 spectrograph. The spark plays between the flat surface to be analysed and a counter electrode of pure aluminium. Calibration was carried out with synthetic solutions. Analyses were also made from absorption measurements based on the colouring of hydrorubeanic acid by copper. The proposed methods of analysis permit the determination of copper between 0·010% and 0·100% with an error of less than 10% of the amount present.

The Spectrographic Determination of Carbon in Steel. F. W. J. Garton. (Spectrochimica Acta, 1947, vol. 3, pp. 68–88 : Chemical Abstracts, 1948, vol. 42, Apr. 20, col. 2544). The possibility of determining carbon in steel by a spectrographic method using a simple condensed spark circuit has been investigated. Preliminary experiments with a rotating mirror were carried out for the purpose of obtaining information concerning the nature of the uncontrolled spark discharge with and without an auxiliary spark gap, and of testing the effect of air blast across the analytical gap. Experimental conditions favouring the emission of C III line 2296·86A were worked out to form with the Fe III line 2295·86A a homologous pair. A number of factors which might adversely affect the accuracy of the determination were investigated. These included the effect of carbon dioxide, the effect of size and shape of electrode, effect of grain size, direction of grain, nature of surface, and effect of metallurgical history. The method is suitable for the simultaneous determination of manganese, chromium, nickel, silicon, molybdenum, and vanadium.

Results Obtained Using an ARL Spectrograph for the Analysis of Steel. P. Coheur and A. Hans. (Revue Universelle des Mines, 1948, Series 9, vol. 4, May, pp. 346–349). Tests on steel samples carried out with an A.R.L. spectrograph in order to study the precision of this apparatus are described. Final results show that the mean quadratic errors are Ni 1·75, Cr 1·30, Mn 1·30, Si 1·57, and Cu 1·55.—R. F. F.

Description of the ARL Spectrograph Used at the Centre Belge de Mètallurgie Physique. L. Habraken. (Revue Universelle des Mines, 1948, series 9, vol. 4, May, pp. 328–333). The spectrograph made by the Applied Research Laboratories, Glendale (California), and in use at the Centre Belge de Métallurgie Physique, is described.—R. F. F.

Method of Estimating Chromium in Ferro-Chromium. R. Lannet. (Revue de Métallurgie, Mémoires, 1947, vol. 44, Nov.–Dec., pp. 380–381). The ferrochromium is dissolved in phosphoric acid. The chromium, as chromic acid, is titrated with ferrous sulphate, using diphenylamine as oxidation-reduction indicator.

Polarographic Determination of Titanium in Ferrous Metals. A. M. Zan'ko, B. A. Geller, and A. D. Nikitin. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 299–300 : Chemical Abstracts, 1948, vol. 42, May 20, col. 3281). The method is suitable for steels and cast irons containing 0·1% of titanium and over ; the analysis requires 20–25 min and the results are within 5% of the truth. Dissolve 0·2 g of steel or cast iron in 5–5·5 ml of 9*N* H_2SO_4, add 1 ml. of 7·5*N* HNO_2 and heat to H_2SO_4 fumes. Dissolve the residue in water, add 3·5 g of NaK tartrate, and dilute with water to 25 ml. Transfer part of the solution into an electrolyser, add one drop of KSCN solution, and reduce the Fe^{+3} with aluminium dust by heating to disappearance of red coloration. Cool the solution, blowing nitrogen through it for 5–7 min, and then make the polarographic test. Satisfactory results were obtained with cast irons containing about 1% of titanium and also standard steel containing 0·4% of titanium and 17% of chromium (chromium did not interfere). The calculation of the Il'kovich equation is described.

The Determination of Manganese in Malleable and Gray Cast Iron with the Steeloscope. M. M. Averbukh and I. I. Erina. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 181–184 : Chemical Abstracts 1948, vol. 42, Apr. 20, col. 2542). Comparison of manganese lines in the 4760, 6020, and 4451 regions with neighbouring iron lines permits estimates of manganese concentrations in the range 0·1–1·0%. An analysis takes 2 min ; agreement with chemical analysis is excellent.

Estimation of the Composition of Oxidising Slags in Electric Arc Furnaces. A. M. Samarin, A. Yu. Polyakov, and L. A. Shvartsman. (Bulletin de l'Académie des Sciences (U.R.S.S.), Classe des Sciences Techniques, 1947, Dec., pp. 1639–1648). [In Russian].

A Discussion on Routine Chemical Methods for the Analysis of Niobium and Tantalum Bearing 18/8 Steels. B. Rogers. (Metallurgia, 1948, vol. 37, Apr., pp. 326–330). A brief review of the essential chemical principles involved in the determination of niobium, tantalum, and tungsten in steel is followed by descriptions of and discussions on : (1) T. R. Cunningham's procedure for estimating niobium and tantalum in 18/8 steels and its application to such steels when up to 0·6% of tungsten, up to 0·1% of titanium, and molybdenum are present ; (2) the analysis of niobium, tantalum, and tungsten steels when the tungsten exceeds 0·6% ; and (3) the determination of any of the additional elements cobalt, copper, tin, and selenium, which normally do not interfere with the foregoing determinations.—A. E. C.

Rapid Routine Method for Testing Stainless Steels. J. B. Culbertson and R. M. Fowler. (Steel, 1948, vol. 122, May 24, pp. 108, 110, 113). Working details are given for the colorimetric determination of chromium, nickel, and manganese in alloy steels, using a Beckman spectrophotometer.—M. A. V.

Take Guesswork out of Metal Identification. G. Black. (Products Finishing, 1948, vol. 12, May, pp. 30–38). Simple tests for distinguishing between aluminium and magnesium, and between stainless and carbon steel are described. For the latter, the response of the material to a magnet and to a drop of nitric acid is noted.—R. A. R.

A Study of the Hydrogen, Oxygen, and Nitrogen Contents of Foundry Pig-Iron. J. E. Hurst and R. V. Riley. (Journal of The Iron and Steel Institute, 1948, vol. 159, June, pp. 130–136).

Method of Hot Extraction for Determining Hydrogen in Steel. V. A. Zhabina. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 275–281 : Chemical Abstracts, 1948, vol. 42, May 20, col. 3283). A simple vacuum resistance furnace was constructed to obtain temperatures as high as 3000° for determining hydrogen by hot extraction at high temperatures. The service life of the heater can be extended to 8–10 months. The chief components of the furnace are shown ; details will be given in a future paper dealing with determination of hydrogen, oxygen, and nitrogen in high-alloy steels. Two apparatus for determining hydrogen at low temperatures (up to 900°) are described. In one apparatus the hydrogen is determined by measuring the pressure drop after gases have passed over heated CuO and through P_2O_5 solution ; in the other apparatus the extracted gases are collected and analysed for their components.

Comparative Evaluation of Methods for the Hydrogen Determination in Metals. Yu. A. Klyachko. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 282–287 : Chemical Abstracts, 1948, vol. 42, May 20, col. 3282). Of the methods for determining dissolved hydrogen in steel in the course of smelting, the most satisfactory one is that in which the gas evolved by the solidifying metal is caught in a vacuum. Of the apparatus for determining the gases by this method, the most advantageous ones are that of Soler, which is widely used in the U.S.A. and that of Samarin which is widely used in the Soviet Union.

Determination of Hydrogen in the Course of Smelting. V. I. Yavoĭskiĭ. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 262–275 : Chemical Abstracts, 1948, vol. 42, May 20, col. 3283). The Herty sampler was modified to make possible sampling from the furnace or from under the slag. Aluminium strip or wire (1–1·5 mm) and weighing 0·8–1% of the sample is so positioned in an arm (8–10 mm in dia) of the sampler that the stream of molten metal comes in contact with the aluminium before it enters the arm. The metal in the arm is used to determine hydrogen by the oxidation method, by using an improved oxidation apparatus ; the oxygen and nitrogen are determined in the metal of the upper part of the sampler. The process of melting and oxidation can be regulated not only by the strength of the high-frequency current but also by regulating the height at which the specimens are suspended. Experiments with molten iron containing carbon 0·02%, using a high-frequency vacuum furnace, have shown that, the addition of aluminium does not affect the solution of hydrogen and that only for aluminium concentrations of over 0·75% does the solution of hydrogen begin to decrease.

Determination of Hydrogen in Steel. A. N. Morosov. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 1485–1487). [In Russian].

Evaluation of the Method of Oxidation [for Determining Hydrogen in Steel]. F. K. Gerke. (Zavodskaya Laboratoriya, 1948, vol. 13, p. 298 : Chemical Abstracts, 1948, vol. 42, May 20, col. 3283). Gerke claims that the method of determining hydrogen proposed by Yavoĭskiĭ (*see* preceding abstract) is essentially the same as that proposed by Gerke. Results obtained by both methods are the same but Gerke claims greater accuracy for lower hydrogen contents.

Critique of the Oxidation Method [for Determination of Hydrogen]. B. A. Shmelev. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 289–292 : Chemical Abstracts, 1948, vol. 42, May 20, col. 3283) (*See* preceding abstracts). Use of metal from the upper part of the sample for determining nitrogen is considered incorrect because only a part of the nitrogen is fixed in this part. Instead, shavings for analysis should be taken from the lower, narrower section. Also, part of the hydrogen is lost in the course of preparing the sample for the determination. Composition of gases in the lower section of the sample should be compared with results obtained by the method of hot extraction, with and without addition of aluminium.

Methods of Oxidation and Hot Extraction in Determining Hydrogen in Metals. G. I. Chufarov and S. S. Nosyreva. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 287–288 : Chemical Abstracts, 1948, vol. 42, May 20, col. 3283). The determination of hydrogen by oxidation of the metal with oxygen at moderate temperatures has a limited field of application. The method cannot be used for high-carbon steels because of the absorption of CO_2 by the plugs in the absorption tubes containing P_2O_5. It is also impossible to determine hydrogen by this method at temperatures of 800–1000° in the case of Nichrome, heat-resistant steels, and many other metals and ferrous alloys, because of the formation of a non-porous oxide film which prevents the penetration of the oxygen to the metal surface and the diffusion of the water vapours in the opposite direction.

Prerequisites for the Accurate Determination of Hydrogen [in Metals]. A. M. Dymov. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 292–295 : Chemical Abstracts, 1948, vol. 42, May 20, col. 3283). In establishing a satisfactory method for determining hydrogen in metals, it is necessary to consider : (*a*) Progress of smelting before the sample is taken, (*b*) dimensions and form of the mould which will result in most uniform cooling for the given grade of steel ingot, (*c*) sections of the ingot to be sampled, (*d*) form and dimensions of the sample, and (*e*) preparation of the sample for analysis. A comparative study should be made of the best methods of determining hydrogen for various groups of steels and not for steels in general. Consideration should be given to the physicochemical properties of the steels as they affect the gas to be determined.

Determination of Combined Nitrogen in High-Alloy Steels and some Ferro-Alloys. B. A. Generozov. (Zavodskaya Laboratoriya, 1947, vol. 13, pp. 314–324 : Chemical Abstracts, 1948, vol. 42, May 20, col. 3284). In determining combined nitrogen in high-alloy steels and some ferro-alloys containing tungsten, chromium, titanium, vanadium, manganese, silicon, and niobium, the results are low because of the inertness or difficult solubility of some nitrides. To overcome this, a two-stage method of dissolving the samples is proposed. First treat the sample with a mixture of H_3PO_4 4, H_2SO_4 1, and water 2 parts ; to prevent loss of NH_3 during this stage, attach to the flask a trap containing water with a few drops of HCl or H_2SO_4. Then evaporate until acid fumes form, add 2 g of dry $K_2S_2O_8$ in small portions. To dissolve the residual nitrides, add 3 g of K_2SO_4 and heat the solution until heavy fumes of H_2SO_4 are evolved. Continue heating until all the residue is dissolved. To determine the nitrogen, steam-distil after adding NaOH for 1·25–1·50 hr until at least 150–200 ml are collected in a known volume of standard H_2SO_4 and titrate the acid in the presence of methyl red and methyl blue.

Investigation of the Carbides in High Alloy Tool Steels. V. I. Arkharov, I. S. Kvater and S. T. Kiselev. (Bulletin de l'Académie des Sciences de l'U.R.S.S., Classe des Sciences Techniques, 1947, pp. 749–756 [in Russian] : Chemical Abstracts, 1948, vol. 42, May 20, col. 3304).

Method for Determination of Carbides in Alloy Steels. M. M. Shapiro. (Zavodskaya Laboratoriya, 1947, vol. 13, Dec., pp. 1425–1430). [In Russian].

Methods for Separation of Carbides from Ferrous Alloys. G. A. Medvedeva. (Zavodskaya Laboratoriya, 1947, vol. 13, Dec., pp. 1413–1421). [In Russian].

Gravimetric Determination of the Carbide Phase in Carbon Steels. N. M. Popova and M. F. Rybina. (Zavodskaya Laboratoriya, 1947, vol. 13, Dec., pp. 1421–1425). [In Russian].

A Study of the Cobalt-Ferricyanide Reaction with Relation to the Determination of Cobalt in Steel. B. Bagshawe and J. D. Hobson. (Analyst, 1948, vol. 73, Mar., pp. 152–157). A critical survey of the method of potentiometric titration of the cobaltous ion with ferricyanide in ammoniacal citrate solution has been made. The normal oxidation potentials for the $Co^{''}$-$Co^{'''}$ and the $Fe(CN)_6^{''''}$-$Fe(CN)_6^{'''}$ systems have been determined and it is shown that the low value for the equilibrium constant of the reaction system accounts for incomplete titration at the point of inflection, and for a rapid decrease

of sharpness of inflection with increasing cobalt concentration. The corresponding simultaneous oxidation of manganese according to the reactive $2MnO + O \rightarrow Mn_2O_3$ has been generally confirmed for steel solutions, but inconsistencies have been noted and in pure manganous salt solution there has been evidence of the reaction proceeding $3MnO + O \rightarrow Mn_3O_4$. Tervalent chromium causes error, but there is no interference from hexavalent chromium. Cobalt determinations have been made on a series of plain and alloy steels covering low to high cobalt contents, and the results compared with values obtained by the nitroso-R-salt absorptiometric method. The comparison shows variable divergencies from the absorptiometric values but may come within acceptable routine tolerance limits.

Swiss Association for Testing Materials. (Schweizer Archiv, 1948, vol. 14, Mar., pp. 94–96). Details are given of the SVMT (Schweizerischer Verband für die Materialprüfungen der Technik) proposed standard procedures for determining copper, nickel, and chromium in steel, and molybdenum in vanadium-free steel. R. A. R.

Colorimeters—A Comparative Investigation of Different Instruments. C. Engel. (Chemisch Weekblad, 1948, vol. 44, June 5, pp. 309–312). [In Dutch].

Modern Methods of Gas Analysis. Part VI—The Haldane Apparatus. Part VII—The Graham-Lawrence Apparatus and the McLuckie Gas Detector. Part VIII—Detection and Estimation of Impurities in Industrial Gases. W. D. Vint. (Metallurgia, 1947, vol. 36, Sept., pp. 276–278; Oct., pp. 333–334; 1948, vol. 37, Jan., pp. 150–152; Apr., pp. 317–318). Continuation of a series of articles (*see* Journ. I. and S.I., 1947, vol. 157, Oct., p. 317).—R. A. R.

Determination of Titanium in Refractory Materials. N. O. Zeldine and S. T. Balyouk. (Zavodskaya Laboratoriya, 1946, vol. 12, No. 7–8, pp. 757–758: [Abstract]. Chimie et Industrie, 1948, vol. 59, June, p. 575). The photocolorimetric determination of TiO_2 in refractory materials is described. A filter is chosen which allows the passage of rays especially absorbed by the solution being studied, and standard curves for the determination of TiO_2 in the sample, are plotted. The preparation of solutions varies according to the product to be analysed. In the case of clay or fireclay, the ground and dried sample is melted in a platinum crucible with Na_2CO_3. Water is added, the solution filtered, and the deposit dissolved in 20% H_2SO_4. For dinas or quartzite, the sample is treated with HF and H_2SO_4 and evaporated to dryness. The residue is melted with potassium pyrosulphate and dissolved in 20% H_2SO_4. In both cases 3% H_2O_2 is added to the sulphuric solution obtained, which is then diluted to a determined volume. With TiO_2 contents smaller than 1% this method is superior to the usual visual method, and is equallly good for higher TiO_2 contents. Error for total titanium up to 2%, varies between 0·04% and 0·08%; for 5–5·5% titanium, between 0·04% and 0·12%.

INDUSTRIAL USES AND APPLICATION

Latest Uses of Alloy Steels in Motor Vehicles. M. J. Day. (Automotive Industries, 1948, vol. 98, Apr. 1, pp. 26–27, 58).

Uses of Special Steels. P. Montereau. (Métallurgie, 1948, vol. 80, Apr., pp. 13, 15; May, pp. 15,17). In the first part the author reviews generally the present-day uses of special steels and refers to the effect of alloying elements such as chromium and tungsten. The kinds of special steel required for specific purposes are discussed. In the second part he outlines some of the properties and uses of chromium, nickel, molybdenum, stainless and structural steels.—J. C. R.

Recent Applications of Nickel Steels and Cast Irons in the United States. (Revue du Nickel, 1947, July-Sept., pp. 33–39. [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Apr., p. 2). A review is presented of some applications in the United States of nickel steels, and includes references to structural and stainless steels.

Nickel Cast Irons. (Revue du Nickel, 1947, July-Sept., pp. 39–43). [Abstract]. Aperçu de la Presse Technique, 1948, vol. 3, Apr., p. 2). This is an account of the use of nickel alloys, more especially cast irons, with examples of American practice. High-duty, white and austenite cast irons are dealt with.

The Present Position in the Development of High-Pressure Steam Turbines. H. Mayer. (Technik, 1948, vol. 3, Apr., pp. 145–152).

Airscrew Turbines. (Iron and Steel, 1948, vol. 21, May 13, pp. 186–188). The ferrous materials used in the Armstrong Siddeley "Mamba" airscrew turbine include a variety of low alloy steels as well as those of higher alloy content, such as DTD49B (Cr 12–16%, Ni 10%, W 2–4%) and G18B (Cr 13%, Ni 13%, Co 10%, Nb 3–3·5%, W 2·5%, Mo 2%).—J. P. S.

Design Trends in Modern Marine Power Plants. F. V. Smith. (Iron and Steel Engineer, 1948, vol. 25, Apr., pp. 92–97). The solutions of the problems of high-pressure high-temperature steam turbines and of gas turbines are primarily metallurgical.—J. P. S.

Bearing Construction with Cast Iron as Anti-Friction Material. M. S. Karpyshev. (Vestnik Machinostroenia, 1946, vol. 16, No. 11–12, pp. 24–29: [Abstract]. Engineers' Digest (N.Y.), 1948, vol. 5, Mar.–Apr., p. 153).

Development in the Construction of Metal Bridges. F. Stussi. (Revue Technique Luxembourgeoise, 1948, vol. 40, Apr.–June, pp. 56–63). The construction of bridges is discussed starting from the early cast-iron bridges through the wrought-iron and mild-steel ones to the present-day bridges made of high-tensile steel such as the Swiss St 37 steel. Examples of various types of bridges illustrate the different stages of development.—R. F. F.

New Metals for Old. Sir Edward Appleton. (Edward Williams Lecture: Proceedings of the Institute of British Foundrymen, 1946–47, vol. 40, pp. A20–A29). The author shows how, during the last fifty years, many metals and combinations of metals have taken the place of others in the manufacture of things that people require and use. Illustrations are given of the way in which scientific enquiry and experimental measurement, with occasional empirical enterprise, have led to the discovery of better metals for practical use.—R. A. R.

The Mechanics of Locked-Coil Wire Ropes. J. A. L. Matheson. (Engineering, 1948, vol. 165, June 18, pp. 578–581; June 25, pp. 601–604).

HISTORICAL

The History of British Steel. L. Sanderson. (British Steelmaker, 1947, vol. 13, Sept., pp. 469–473; Oct., pp. 521–525; Nov., pp. 569–573; Dec., pp. 614–618; 1948, vol. 14, Jan., pp. 42–47; Feb., pp. 86–91; Mar., pp. 134–139; Apr., pp. 180–185). The history of the manufacture of iron and steel in Great Britain is traced from the Roman occupation up to the present time.—R. A. R.

The Wire-Drawers of Bristol 1312–1797. H. R. Schubert. (Journal of The Iron and Steel Institute, 1948, vol. 159, May, pp. 16–22).

Portsmouth Steel Corporation. K. B. Lewis. (Wire

and Wire Products, 1948, vol. 23, Mar., pp. 227–233, 266). The history of the development of the Portsmouth Steel Corporation, wire manufacturers at Portsmouth, Ohio, is given.—R. A. R.

ECONOMICS AND STATISTICS

The Norwegian Foundry Industry. J. Sissener. (Foundry Trade Journal, 1948, vol. 84, May 27, pp. 515–516). The industry in Norway is surveyed from an economic viewpoint.—M. A. V.

Japan—Proposed Increase in Authorised Level of Industry. (British Iron and Steel Federation, Monthly Statistical Bulletin, 1948, May, pp. 5–9). Implementation of the present recommendations of a special U.S. War Department Committee on Japanese industry would mean retention by the Japanese iron and steel industry of all existing blast-furnace, steelmaking, and rolling-mill capacity to the extent of 4·5 million, 8 million, and 10·9 million metric tons respectively.

Statistical Information—Extract of Report at Järnverksföreningens Meeting at Orebro, January 30, 1948. (Jernkontorets Annaler, 1948, vol. 132, No. 4, pp. 115–122). [In Swedish]. Tables are presented of the Swedish production and exports of iron ore, pig iron, and manufactured iron and steel as well as the imports of crude, semi-finished, and finished iron and steel.—R. A. R.

Steel from Rhodesian Iron Ore. (Mining Journal, 1948, vol. 230, May 8, p. 333). A brief account is given of the mineral resources and the geographical and economic conditions which have led to the establishment of the new Riscom (Rhodesian Iron and Steel Commission) works at Que Que half-way between Bulawayo and Salisbury. The industry is based on the banded hematite in that district. A small blast-furnace plant with ancillaries large enough to meet contemplated expansion is already producing iron and the first steel ingots will shortly be poured.—R. A. R.

The Systematic Reduction of Metal Production Costs. (Stal, 1948, No. 3, pp. 195–199). [In Russian]. Production costs in various metallurgical works of the U.S.S.R. are compared and the need for greater economy in metallurgical processes is indicated.—S. K.

MISCELLANEOUS

Hoisting Rope Research in Ontario Mines. R. G. Dye, R. D. Parker, and R. L. Healy. (Canadian Mining and Metallurgical Bulletin, 1948, vol. 41, May, pp. 158–171). The researches being undertaken under the auspices of the Committee on Hoisting Ropes of the Ontario Mining Association are described in detail. Corrosion is the most serious problem; it may be minimized by reducing the quantity of corrosive water and exhaust air in the shaft as far as possible, and applying frequent dressings of grease. Considerable progress has been made in research on lubricants. Rope slip is increased by making the ratio of drum and sheave diameter to rope diameter at least 80. Suitable types of safety dogs for personnel cages in vertical shafts are described, and a safety factor of 8·5 is recommended at the point of connection of the rope to the conveyance. M. A. V.

New Research and Development Laboratories Opened by Canadian Westinghouse Co., Ltd. (Canadian Metals and Metallurgical Industries, 1948, vol. 11, Mar., pp. 16–17). New chemical, physical, electrical, and metallurgical laboratories are briefly described.—M. A. V.

Steel and Tinplate—How Scientific Research Has Helped the Welsh Industries. H. Leighton Davies. (Iron and Steel, 1948, vol. 21, May, pp. 122–123, 132). The author describes the co-operation between the South Wales Siemens Steel Association, the Welsh Plate and Sheet Manufacturers' Association, the Department of Scientific and Industrial Research, and the University College of Swansea in developing scientific research, before the foundation of the British Iron and Steel Research Association. He states that this co-operation was of great value to the industry and to university staffs and graduates.—J. P. S.

New Swedish Metal Research Institute. C. O. Lissell. (Foundry Trade Journal, 1948, vol. 84, May 20, pp. 491–492). The new Metallografiska Institut in Stockholm is described.—M. A. V.

Engineering the Tin Can. H.-S. Van Vleet. (Mechanical Engineering, 1948, vol. 70, Apr., pp. 315–320). This paper describes the manufacture of the modern tin can, the use of electrolytic tinplate, and the necessity for lacquering with certain types of contents.—J. P. S.

Texturized Metals Find Wide Application. A. H. Allen. (Steel, 1948, vol. 122, May 24, pp. 94–97, 119, 120). The applications of design-strengthened, or "texturized" metals are described, and data given to show the increase in rigidity, buckling resistance, impact, and tensile strengths obtained by this method of processing. M. A. V.

Vacuum Metallurgy. H. A. Knight. (Scientific American, 1948, vol. 178, Apr., pp. 173–175: [Abstract]. Metals Review, 1948, vol. 21, May, p. 4). An account is given of melting metals in the absence of gases to produce high-quality products.

Prevention of Mechanical Failures in Steel Plant Equipment. O. J. Horger and G. A. Stumpf. (Iron and Steel Engineer, 1948, vol. 25, May, pp. 69–77). Examples are given of the methods adopted to prevent failures in steelworks equipment. In several cases fatigue failure was prevented by rolling the surfaces at positions of stress concentration. Changes in the types of steel used for mandrels in tube rolling, and in the design of roll-drive coupling boxes, chipping chisels, and other equipment prolonged their life.—R. A. R.

BOOK NOTICES

GARRIDO, J. and J. ORLAND. "*Los Rayos X y la Estructura Fina de los Cristales. Fundamentos Teoricos y Metodes Practicos.*" Prologo del Julio Palacios. 4to, pp. xiii + 260. Illustrated. Madrid, 1946: Dossal, S.A. (Price 148 pesetas).

The purpose of this book is to expound the basic theories and practical methods used in research into the fine structure of crystallized matter, particularly the application of X-ray diffraction to the determination of crystal structure.

The first part, which contains four chapters, is of a theoretical nature: it explains and discusses the various theories regarding the nature of X-rays and their scattering by material obstacles. The first chapter studies the nature of the continuous spectrum and of characteristic radiation. After discussing the different structures of the atom propounded by Rutherford, Bohr, and Sommerfeld, and the Bohr magnetons, it explains the energy levels, the origin of characteristic radiation and the influence on this of the voltage and atomic number. The second chapter deals with the scattering of X-rays by one or more electrons, or by atoms; it defines the scattering coefficient by one or more electrons, and the mass

and atomic scattering factors; it discusses Thomson's theory, and expounds those of Thomas, Fermi, and Hartree; finally, it describes R. W. James's and G. W. Brindley's tables of atomic scattering factors. The third chapter deals with the fundamentals of crystallography, which are necessary for the understanding of X-ray spectra. The fourth chapter, the longest of this part, studies the X-ray scattering by crystals. The Bragg method, and Laue theory, the reciprocal lattice, the scattering vector, the structure amplitude, X-ray absorption and refraction, integrated reflection, extinction, the temperature factor, and the scattering of X-rays with change of wave-length, etc., are the different subjects dealt with in this chapter; these are illustrated by several examples.

The second part is most important, and most useful to the reader who wishes to learn how to proceed methodically with the determination of fine crystal structure. The fifth chapter describes the Bragg, Laue, Weissenberg, rotating-crystal and powder methods for the determination of crystal structure, the Buerger method for the photography of the reciprocal lattice, and the ionization and photographic methods for measuring the intensity of spectra. The sixth chapter, the title of which is "Course of the Structure Determination," comprises the following subjects: Selection and preparation of the material; determination of the symmetry; its determination from physical properties, and by means of Laue's diagrams; observations on the determination of the symmetry; determination of the crystallographic constants; selection of the method; determination of the dimensions of the elementary cell; determination of the number of atoms contained in it; determination of the net type and the rules of extinction; determination of the axis of the definitive elementary cell; determination of the Bravais group; elements of symmetry and extinction; extinction tables; observations on the determination of the space group; determination of the atoms' co-ordinates; the Fourier method; the Fourier-Patterson method; and the checking of the structure. Chapter seven develops four examples of the determination of structure of gradually increasing difficulty: copper, brucite, rutile, and manganite. The copper structure is a fixed symmetry; for the determination of the structure of brucite, one has to seek the value of only one parameter; the rutile crystal is determined by the Fourier method; and, finally, the manganite example is of a somewhat complex structure.

In the third part, chapter eight gives the crystal structure, non-metals, and noble gases; the atomic and ionic radii; and the physical properties of all the elements arranged in order of atomic number. The ninth chapter explains the different types of atomic groups: finite, chains, plane net, and space net. The last chapter, which is devoted to the study of crystalline aggregates, describes the method for determining the textures, and shows in a series of Debye diagrams the effect of the temperature on the grain growth and on the elimination of textures. (From the metallographic point of view, it would have been very interesting here to have made a study of lattice expansions and contractions under loads lower or higher than that of the yield stress).

The first appendix gives an idea of the double internal reflection of X-rays, and the second reproduces different numerical tables such as trigonometrical and exponential functions, absorption coefficients and atomic factors of the elements.

The seventy-three tables, the numerous examples and photographs distributed throughout the text, enhance the usefulness of this book.

LOW, D. A. "*A Pocket-Book for Engineers.*" Edited by B. B. Low. New Edition. 16mo, pp. 778. Illustrated. London, 1948: Longmans, Green and Co. (Price 15*s.*).

This reference book is too well known for a detailed summary of its contents to be necessary; it will suffice to say that it has been brought up to date, and the sections on Chains, Chain Slings, and Crane Hooks; Manilla and Wire Ropes; Screw Threads; Pipes and Pipe Joints; Steam Tables; and Locomotives have been revised. It should be of value alike to the engineer and to the iron and steel technician.—M. A. V.

NEW PUBLICATIONS

ADMIRALTY, London. "*Boiler Corrosion and Water Treatment* 1945. (*BR.*1335)" F'cap, pp. 33. Illustrated. London: H.M. Stationery Office. (Price 6*s.*).

AMERICAN SOCIETY FOR METALS. "*Fracturing of Metals.*" 8vo, pp. 310. Illustrated. Cleveland, Ohio: American Society for Metals. (Price $5.00).

BECQUEREL. M. J. "*Propriétés Magnétiques Générales de Divers Composés des Elements du Groupe du Fer.*" (Mémorial sciences physiques, No. 49). Pp. 77. Paris, 1947: Gauthier-Villars et Cie.

BEYNON, C. E. "*La Structure Physique des Alliages.*" Traduit de l'Anglais par Suzanne Vell. 8vo, pp. 106. Illustrated. Paris, 1947: Dunod.

F.I.A.T. REVIEW OF GERMAN SCIENCE, 1939–1946. "*Physics of Solids,*" Part I. Senior Author George Joos. 8vo, pp. 228. Berlin, 1947: Office of Military Government for Germany. Field Information Agencies Technical.

GABOR, D. "*The Electron Microscope. Its Development, Present Performance, and Future Possibilities.*" Brooklyn, N.Y.: Chemical Publishing Co. (Price $4.75).

HILTON, B.R. "*Engineering Machine Shop Practice.*" Second Edition, 8vo, pp. x + 189. Illustrated. London, 1946: Sir Isaac Pitman and Sons, Ltd. (Price 6*s.*).

JACOBSON, C. A. "*Encyclopedia of Chemical Reactions.*" Vol. 2. "*Cadmium, Carbon, Cerium, Cesium, Chlorine, Chromium.*" New York: Reinhold Publishing Corp. (Price $12).

LEIGHOU, R. B. "*Chemistry of Engineering Materials.*" 4th Edition. New York: McGraw-Hill Book Co., Inc. (Price $4.50).

MILLENET, L. E. "*Enamelling on Metal.*" 8vo, pp. 126. Kingston Hill, 1947: Technical Press, Ltd. (Price 6*s.*)

MONNOT, G. "*Eléménts de Spectrographie. Applications à la Spectroanalyse Qualitative et Quantitative des Métaux,*" Paris: Dunod.

PAAGMAN. B. J. "*Metaaldraaien*" (De wertuigkundige bibliotheek No. 18) Rotterdam: Nijgh and van Ditmar, N.V. (Price Fl. 3·90).

SCIANDRA, P. "*Les problèmes actuels de la Sidérurgie Française.*" 8vo, pp. 237. Paris, 1947: Tournier et Constans.

TYLER, PAUL M. "*From the Ground Up.*" Facts and Figures of the Mineral Industries of the United States. First Edition. 8vo, pp. viii + 248. Illustrated. New York, 1948: McGraw-Hill Book Co., Inc. (Price $3.50).

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